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Line Item 3
DRD MA-183 TA

EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM

FINAL REPORT VOLUME 2 CONSTRUCTION

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EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM

FINAL REPORT
VOLUME 2
CONSTRUCTION

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July 1980

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FOREWORD

The Extravehicular Crewman Work System is a study of manned extravehicular activity centering about construction and satellite servicing in Earth orbit.

This report is divided into four volumes:

Volume 1	Executive Summary
Volume 2	Construction
Volume 3	Satellite Service
Volume 4	Program Evolution

This volume, Volume 2, Construction, provides an overview of the work performed in the study.

This study program has been performed under contract by Hamilton Standard for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center over a period from April 1977 to June 1980.

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EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 2, Construction

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ACKNOWLEDGEMENTS

The study was conducted at Hamilton Standard with significant contributions made by Dr. Harrison Griswold. We wish to acknowledge valuable comments and input from Mr. William Smith at NASA Headquarters and from Messrs. James Gibson, Alva Hardy, Vernon Bailey, Robert Spann and Manuel Rodriguez of NASA JSC, as well as Dr. Karl Pfitzer of McDonnell Douglas Aeronautics, Messrs. John Scheibel and Kenneth Lambson of ILC-Dover and Mr. William Elkins of Acurex Aerotherm.

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 2, Construction

- Introduction
- Structure Characteristics
- Construction Tasks
- Requirements
- Concept Evaluation
- System Preliminary Design

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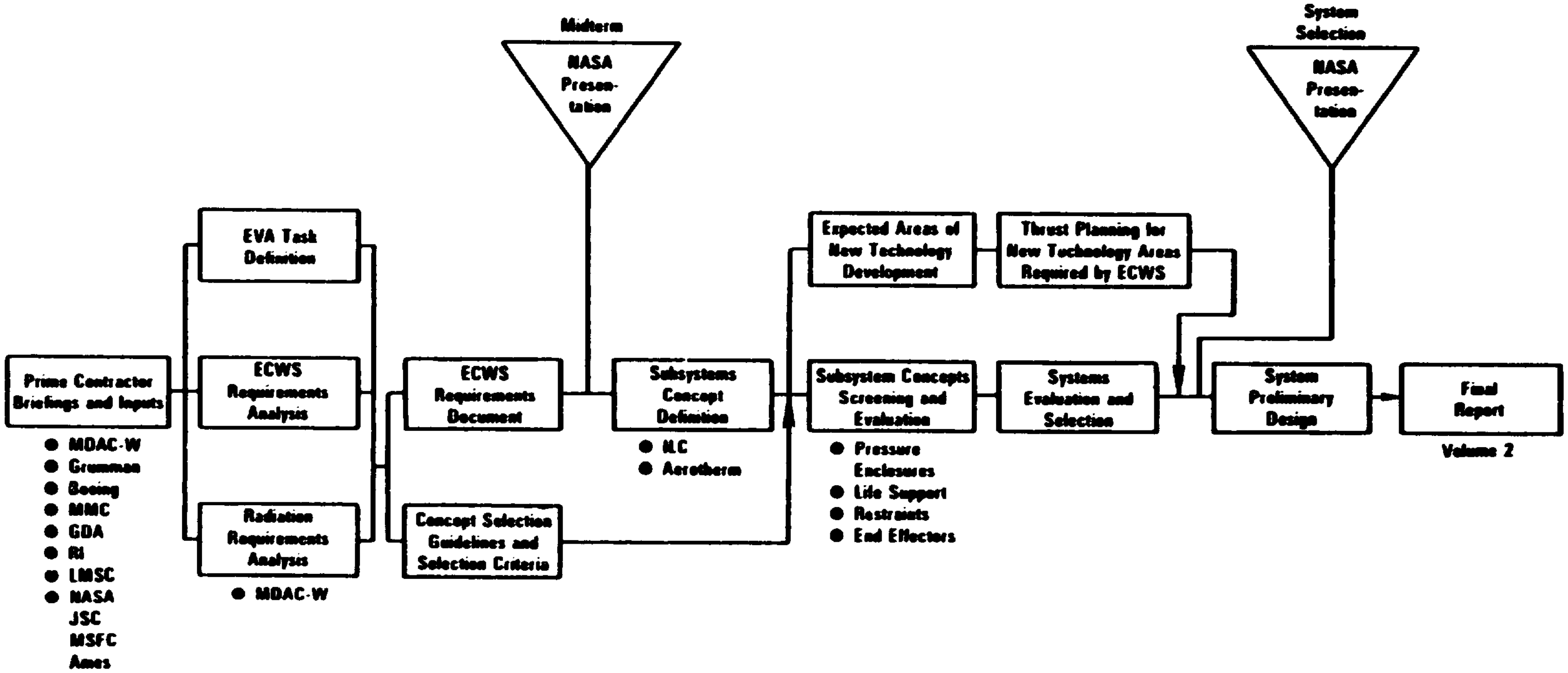
INTRODUCTION

The objective of the construction portion of the Extravehicular Crewman Work System (ECWS) Study Program is to define the requirements and select the concepts for the crewman EVA work system required to support the construction of large structures in space.

The accompanying illustration shows the structure of the construction ECWS portion of the study.

ECWS CONSTRUCTION STUDY FLOW



ECWS CONSTRUCTION REPORT

This ECWS Construction Report covers the following set of study program tasks:

- Identify NASA plans for space construction activity
- Identify EV work tasks
- Define guidelines and performance requirements and develop evaluation criteria
- Define and evaluate alternate configuration concepts
- Recommend for selection the optimum system concept
- Perform preliminary design of selected ECWS concept

EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 2, Construction

Introduction

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SPACE PROGRAM EVOLUTION

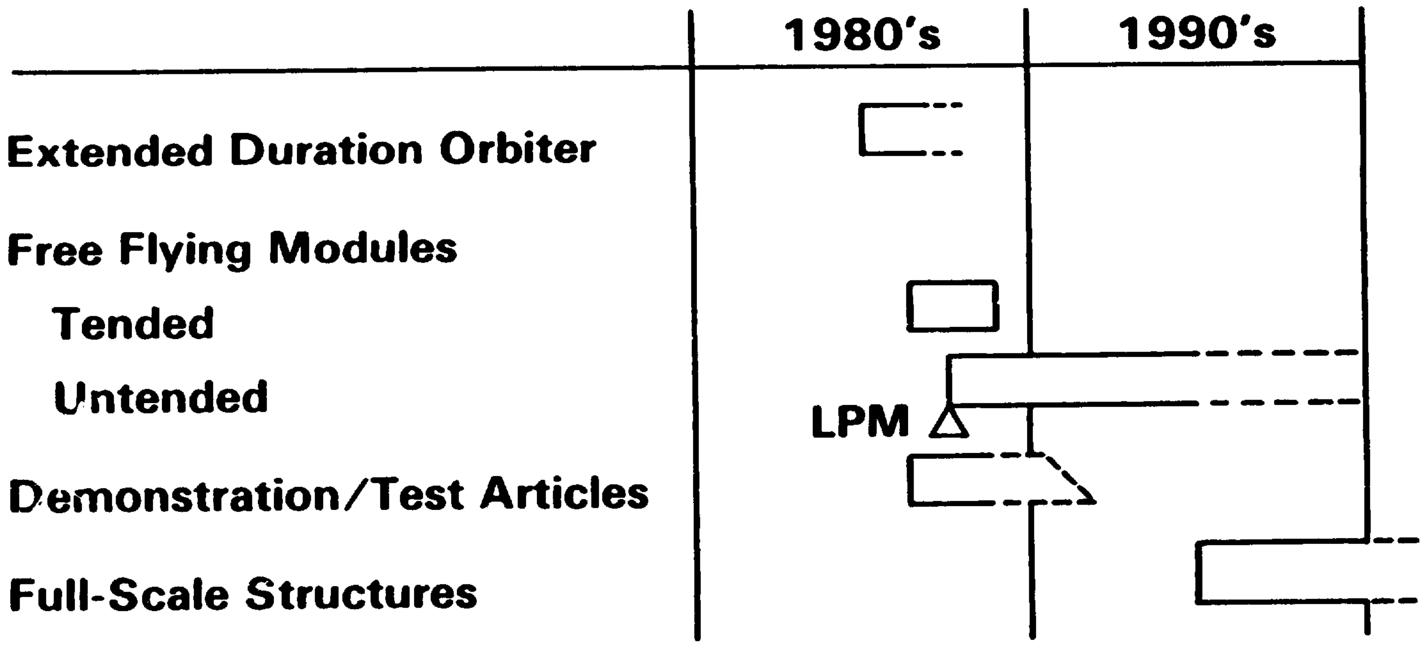
Within the time frames shown the Space Program will evolve towards placement of large structures in orbit in four major steps:

- Extended Duration Orbiter - using Spacelab and small (approx. 25-50 Kw) power module.

- Free Flying Module(s) - initially Shuttle-tended, but later permanently manned (untended by Shuttle) when the approx. 200-500 Kw large power module (LPM) becomes operational.

- Demonstration/Test Articles - built on the free-flying modules(s), this hardware will be used to resolve the construction and technical issues requiring orbital development.

SPACE PROGRAM EVOLUTION



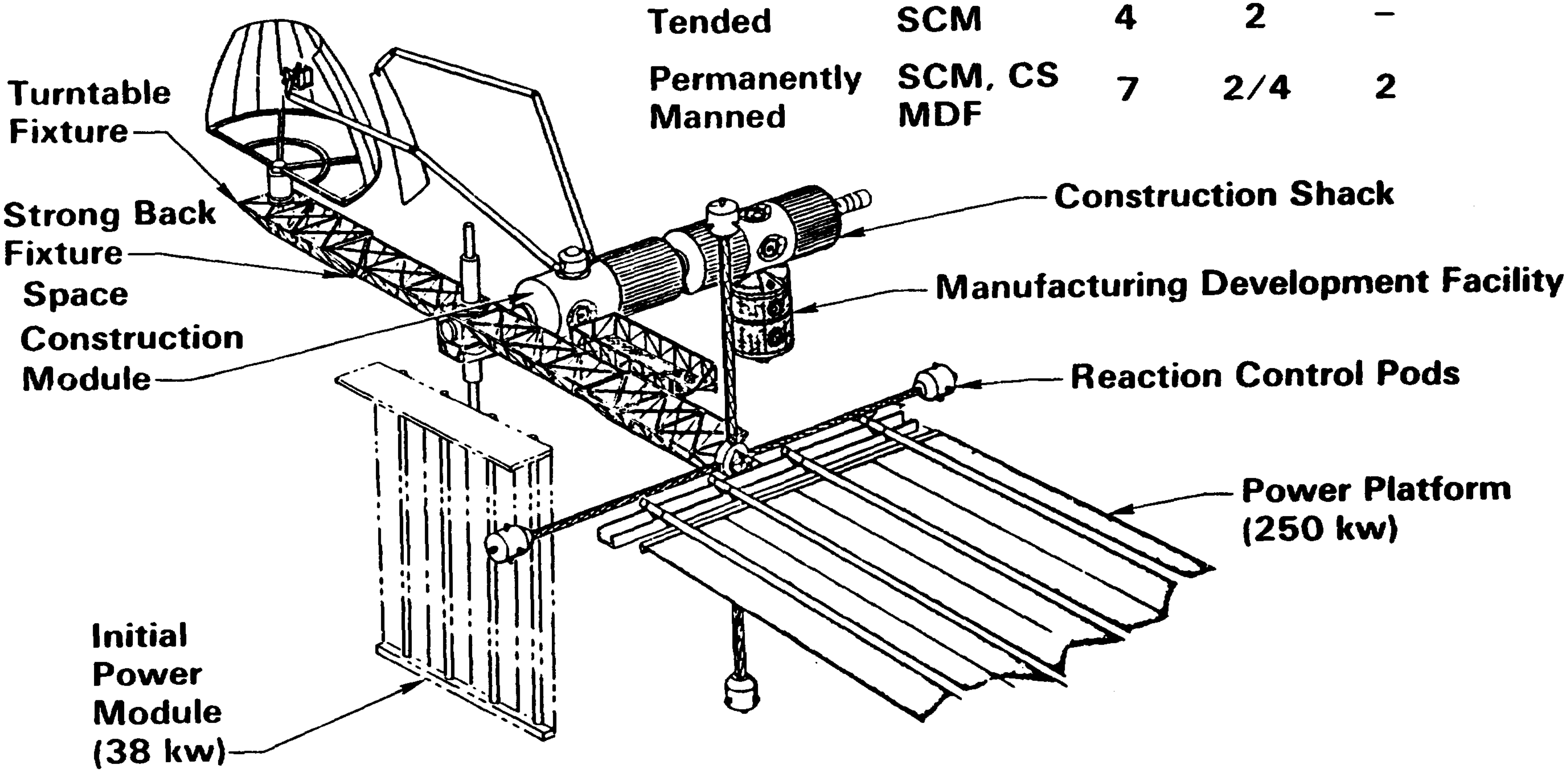
SPACE CONSTRUCTION SUPPORT

The Space Construction Base (SCB) is representative of the free flying modules which are expected to be the point of departure for developing the capability to fabricate large structures in space. The SCB will provide the habitat for the construction crew, and will provide the physical support for the construction activity. The sequence for launching and using such an SCB is as follows:

Shuttle Flt.	Payload	Description/Activity	Comment
1	Power Module	25-38 kW Provides Berthing Ports for Additional Modules	
2-3	Space Construction Module	9.5M Long Module with Construction Control Test Support & Suit Support (Drying, Recharge, Replenishment)	Used with Standard 2-Man A/L
	Crane	(2) 7 DOF Arms on Rotating Base. Operated from Turret or as Cherry Picker. 35m Reach	
4-5	TA-1 Antenna	Begin Construction of TA-1.	1st Use of ECWS
6-7	TA-1 GEO Module + IUS	Complete TA-1 Construction	Use ECWS
8-9	Strong Back + Turntable	Strongback Length Variable Up to 52m	
10-11	Reaction Control Pods		For Attitude Control During Build-Up
12-13	Power Platform Composite Beam Fab Machine	250 kW Fab in Orbit Fab 1m Using Prepreg-Pultrusive Method	Use ECWS
14-15	Construction Shack	16.15m Long Module w/Quarters for 7 Crew, Galley & Waste, ECLS, Comm Data Mgmt, Power Mgmt. Reaction Control POD. 2 Man A/L w/Suits Rescue & MMU Stowage	This Configuration Begins Permanently-Manned SCB Operation
16-19	TA-2 Antenna Beam Mapping Satellite	Construct TA-2 Test TA-7 1 BMS	Use ECWS
20-21	Space Processing Dev Facility	9m Long Derivative of S/L Long Module	
22-23 & Onward	30m Radiometer, 27m Multibeam Lens, 100m Radiometer	Construct & Test 30m Radiometer, 27m Multibeam Lens and 100m Radiometer	Use ECWS

MDAC SCB - GENERAL ARRANGEMENT

Configuration	Modules	Crew Total	Crew EVA	MMU
Tended	SCM	4	2	–
Permanently Manned	SCM, CS MDF	7	2/4	2



EVA INTERFACES

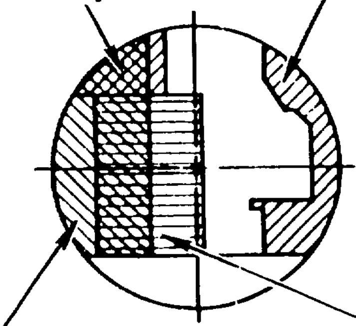
This slide shows typical EVA support provisions contained within a free-flying module. The provisions are based on use of either a standard or modified Shuttle Orbiter airlock, and are concepted to support the present Shuttle EMU. The provisions illustrated are for the MDAC-W Space Construction Base (SCB), which employs a space construction module for orbiter-tended operation and the construction shack for untended (permanently manned) operation.

This information provides an indication of EVA support capability, but does not constrain dimensional considerations of the ECWS, except for hard point design drivers such as hatch diameters that restrict ECWS dimensions.

MDAC-W SCB-EVA INTERFACE

Location	Space Construction Module	Construction Shack
Mode	Tended	Permanently Manned
Airlock	Orbiter Standard 160 cm dia x 211 cm high 4.25 m^3 Hatch 1m dia "D" Shaped	Orbiter Modified 160 cm dia x 211 cm high 4.25 m^3 Hatch 1m dia "D" Shaped
Stowage	Suit Drying & EVA Recharge/Replenishment	EVA Support and Work Bench

1.6 m^3
100 cm Long x
200 cm High x
80 cm Deep



REPRESENTATIVE SPACE STRUCTURES

Twelve representative space structures were studied to typify structure characteristics that drive ECWS task and performance requirements. These structures represent a cross-section of candidate concepts under consideration by various NASA centers and Aerospace Prime Contractors. The following characterizes the structures:

- They represent the extremes of size and weight.
- They represent the variety of proposed construction techniques.
- They all require the ECWS to support their construction.
- They are all so large as to require at least one Shuttle launch.
- They favor on-orbit fabrication or assembly over on-orbit deployment to achieve payload launch high packing density required for economical Shuttle launching.

Structures fall into three groups:

- Large Power Modules

  Large Power Modules to provide free-flying modules with approximately 250 kW of power to support manufacture and test. Projected time for this activity is the late 1980's.

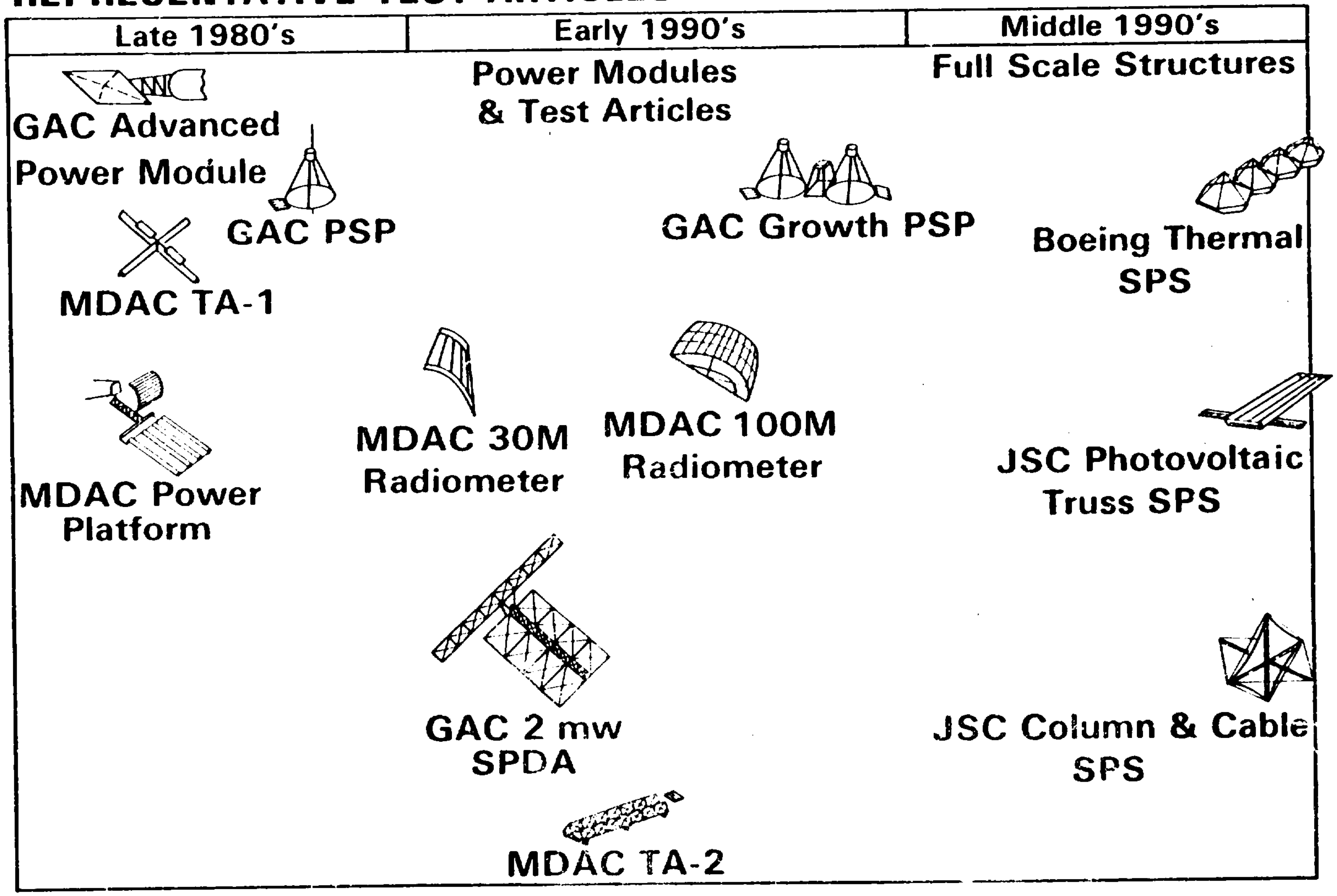
- Structure Demonstration and Test Articles

  A group of development and test structures to develop fabrication techniques and to answer questions relative to thermal and structural stiffness and intended function. Projected projected time for this activity is the late 1980's and early 1990's.

- Full Scale Structures

  The first group of operational solar power satellite systems, communications antennas, and reflectors is expected to be the mid 1990's.

REPRESENTATIVE TEST ARTICLES AND FULL SCALE STRUCTURES



GAC — Grumman Aerospace Corp
MDAC — McDonnell Douglas Aerospace Corp
PSP — Public Service Platform (Communications Satellite)
SPDA — Solar Power Development Article
SPS — Solar Power Satellite
TA — Test Article

SUMMARY OF MAJOR DEMONSTRATION AND TEST ARTICLES

Structure	Projected Construction Techniques	Dimensions		Major Elements									Construction Locale	Major OCSE				
		Size	Wt	Beams	Solar Array	Elect. Cabling	Gimbal Brg.	Brace Cables	Electronics/ Amplitrons	ACS	RF Panels	IUS to GEO		Crane/Cherry Picker	EVA Work Platform	Strongback/ Turntable	Beam Builders	Holding Fixtures
GAC Advanced Power Module	Fab/Dep/ Assy	App 35M + 70M	25K kg	1M	X	X	X		X				Const & Use in LEO	X	X	X	X	
GAC 2 mw SPDA	Assy/ Deploy	Antenna 6M + 200M	8 kg								X		Const & Use in LEO	X	X	X		X
	Fab & Deploy	Solar Array 196M + 111M	24K kg	1M	X	X	X		X	X				X	X	X	X	X
GAC PSP	Not Defined	61M Dia + 61M	27K kg	X		X	X		X	X	X	X	Const in LEO Use in GEO	X	X	X	P	
MDAC TA-1	Fab/ Deploy	Cruciform 123M + 125M	6K kg	2M + 15M		X			X	X		X	Const in LEO Test in GEO	X	X		P	X
MDAC Power Platform	Fab/ Deploy	105M + 28M		1M	X	X	X		X	X			Const & Use in LEO	X	X		X	X
MDAC TA-2	Fab/Assy & Deploy	Solar Array 30M x 250M	22K kg	10M	X	X	X		X	X			Const & Use in LEO	X	X	X	P	X
	Fab & Deploy	Antenna		0.1M							X		Const & Use in LEO	X	X	X	P	X
MDAC 30M Radio-meter	Fab/ Assy	30M Dia	500 kg	1M						X	X		Const & Test in LEO	X		X	P	X
MDAC 100M Radio-meter	Assy	100M Dia x 50M High	2900 kg	1M						X		X	Const in LEO Test in GEO	X	X	X		X
GAC Growth PSP	Not Defined	140M + 61M x 61M		X		X	X		X	X	X	X	Const in LEO Assy to PSP in GEO	X	X		P	X

· = Not Required
X = Required
P = Possibly Required
OCSE = Orbital Construction Support Equipment

SUMMARY OF REPRESENTATIVE DEMONSTRATION AND TEST ARTICLE CONSTRUCTION ELEMENTS

This listing typifies the range of element types that comprise representative demonstration and test articles. This list is drawn from the preceding tabulation of demonstration and test article characteristics, and forms the basis for identifying ECWS tasks and requirements discussed in the following section of this report.

Element	Weight	Dimensions
IUS Stages	30,000 kg	2m Dia. x 20m Long
Cargo Pallets	15,000-30,000 kg	5-20m
Construction Jigs	8700 kg	40 x 110 x 7m
Complete Assemblies	7800 kg	30 x 250m
Composites Fabrication Module	4660 kg	4.4m Dia. x 15m
Brace Cabling	1300 kg	2m Dia. x 1m
Rotary Joint	165 kg	1m x 1m x 1m
Electronics Pkgs	75 kg	0.5m x 0.5m x 0.5m
ACS Pods	60 kg	1m x 1m x 1m
Worksite Platform	25 kg	1.5m x 0.5m x 0.5m

FULL-SCALE STRUCTURE STUDIES

Studies have been undertaken by NASA and the aerospace prime contractors to define concepts for the full scale space structures of the mid-1990's. While not yet definitive, the studies identify and discuss issues such as:

- Construction Locale - LEO or GEO
- Materials - Composites or metals
- Manufacturing Methods - Automated or manual
- Launch and Orbit Transfer means
- Size and Configuration of structure

The following studies indicate the forms that the full scale structures may take. Hence, the studies are useful to the ECWS Study Program to show the types of structures whose construction the ECWS will ultimately be required to support.

STUDY	INTEREST TO ECWS
NASA/JSC - Solar Power Satellite Concept Evaluation	Comprehensive overview of entire SPS idea
Boeing - Solar Power Satellite Concept Construction	Structure/construction concepts
Flexible Spacecraft Structure	Surface Temperature Range -118°C (-180°F) to +93°C (+200°F)
Future Space Transportation Systems	Prototype - 16 men for 1 yr w/90 day stay time Full Scale - 100 men in each of 3 habitats HLLV launch materials to LEO OTV transport to GEO.
GAC -	Materials
Space Fabrication Techniques,	Graphite/Polyimid main structure, Steel cable bracing, Al tube and rod for minor structure.
NASA/JSC -	Candidate Structure Characteristics
Space Solar Power Concepts	Column and Cable, Photovoltaic Truss
MMC Orbital Construction Support Equipment	Identification of structural elements, construction tasks and recommended construction support equipment.

CHARACTERISTICS OF FULL SCALE STRUCTURES

Structure	Construction Techniques	Dimensions Size	Major Elements										Construction Locale	Major OCSE										
			Beams/ Truss	SECS	Power Dist.	Rotary Bearings	Brace Cables	Comm/Inst Electronics	ACS	MPTS Panels	Rancine Cycl Mach.	OTV to GEO		Manipulator $\geq$5 DOF	Large Structure Docking	Cherry Picker	Central Hub Assy/Dep Nod	Long BCOM $\geq$4 DOF	Maint/Repair Module	Commodities Stor. Module	Pers/Matl Xport Struct. Attached	OCSE Storage Panels	Pers/Matl Xport Free Flyer	EVA Module
Boeing Thermal 10 GW SPS	Fab & Assy & Assy	18 km x 4.5 km	Comp 8M x 26M Square & 10M x 388M Triang Mods.	X	X	X	X	X	X	X	X	X	Fab & Assy Each Module in GEO. Join 4 Modules & Ant. in GEO	X	X	X	X	X	X	X	X	X	X	X
JSC Photo Voltaic Truss 10 GW SPS	Fab & Deploy	27.5 km x 5.2 km	Comp 10M in 650M Truss Mode	X	X	X	X	X	X	X	–	X	Fab Major Elements & Const Facilities in GEO. Complete Fab & Assy in GEO	X	X	X	X	X	X	X	X	X	X	X
JSC Column & Cable 10 GW SPS	Fab & Deploy	29 km x 29 km x 14 km	Comp 2.45M in 100M x 200M Mods.	X	X	X	X	X	X	X	–	X	Fab Major Elements & Const Facilities in GEO. Complete Fab & Assy in GEO.	X	X	X	X	X	X	X	X	X	X	X

SPS - Solar Power Satellite
SECS - Solar Energy Collection System (Concentrators & Collectors)
ACS - Attitude Control System
MPTS - Microwave Power Transmission System
OCSE - Orbital Construction Support Equipment

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EVA PAYLOAD-ASSOCIATED TASKS

The construction sequences for representative SPS and PSP test articles were studied to identify the payload operations likely to require EVA. Six categories of structure-oriented operations were recognized:

- Position, install and remove construction equipment
- Position construction material
- Construction, consisting of fabrication, assembly and deployment
- Checkout and Activation
- Use payload for intended purpose
- Maintenance and repair

Within these operations 46 sub-operations were identified as shown in the following matrix.

EVA PAYLOAD — ASSOCIATED TASKS

- Position, Install and Remove Construction Equipment, (EVA Work Station, Restraints, Lighting, Jigs and Fixtures, etc.)
- Position Construction Material
  (Position Cargo Pallets, Move Cargo Items)
- Construction
  (Fabricate Structure Elements, Assemble Structure Modules, Deploy Solar/Reflector Blankets, Install Components)
- Checkout and Activation
  (Use Alignment and Test Instruments and Fluid Servicing Equipment)
- Use the Structure or Payload for Its Intended Purpose
  (Install/Remove Experiments , Operate Controls)
- Maintenance and Repair
  (Transfer Fluids, Repair Damage, Replace Assemblies)

CREWMAN-ORIENTED EVA TASKS

EVA Payload - Associated Tasks	Cut/ Trim	Make Holes	Fasten-Mechanical	Fasten-Weld/ Fuse Bond	Align	Checkout	Clean/ Service	Replenish Fluids	Manipulate Small Objects	Position Medium Size Objects	Position Large Objects
Position, Install and Remove Construction Equipment (4)											
Deploy and Remove Portable EVA Work Station										X	X
Install and Remove Restraints at EVA Work Station			X						X	X	
Install and Remove Lighting										X	
Position, Install and Remove Assembly Jigs and Fabrication Modules			X		X				X	X	X
Position Construction Material (3)											
Position Cargo Pallets					X					X	X
Move Cargo Pallets										X	
Move Cargo Items Between Work Site Storage Area and Construction Site										X	
Construction (24)											
Translate to EVA Worksite										X	
Secure Tool Box at EVA Worksite, Stow and Retrive Tools			X							X	
Handle Construction Instructions									X		
Cut with Saw (Hand or Power)	X								X		
Drill/Punch		X							X		
Install Staples/Spring Clips		X	X						X		
Weld/Solder				X					X		
Apply Electrical Insulation									X		
File/Deburr	X								X		
Cut Cable	X								X		
Use Hand Tools	X	X	X						X		
Install Nuts/Bolts/Washers/Rivets			X						X		
Deploy Folded Structure					X				X		
Apply Surface Treatment (Finishes/Bonding Agents)				X					X		
Install Structural Assembly or Component			X	X	X				X	X	X

CREWMAN-ORIENTED EVA TASKS

EVA Payload – Associated Tasks	Cut/ Trim	Make Holes	Fasten Mechanical	Fasten-Weld/ Fuse-Bond	Align	Checkout	Clean/ Service	Replenish Fluids	Manipulate Small Objects	Position Medium Size Objects	Position Large Objects
Clamp Structural Assembly			X						X	X	X
Align Structure									X	X	X
Collect & Store Debris									X		
Unroll Wire/Cable Reels											X
Unroll Large Solar/Reflector Blankets											X
Tool Tool Bit Changeout									X	X	
Mate & Demate Electrical/Fluid Connections									X		
Use Marker Pen									X		
Install Cable Assemblies				X					X	X	X
<u>Checkout and Activation (5)</u>											
Connect and Use Functional & Leakage Test Instruments						X			X	X	
Perform Dimensional Measurements									X	X	
Mate & Demate Electrical/Fluid Connectors						X			X		
Check & Adjust Cable Tension						X			X		
Set & Reset Electrical Switchgear									X		
<u>Use Payload (2)</u>											
Install/Remove Experiments									X	X	
Operate Controls									X		
<u>Maintenance/Repair (8)</u>											
Apply Lubricants									X		
Transfer Fluids/Fuel/Pressurants								X	X	X	
Use Cleaning Agents							X		X		
Mate & Demate Electrical/Fluid Connectors								X	X		
Clean, Service, Align Beam Fab/Assy Equipment					X				X		
Perform Minor Repairs to Beam Fab/Assy Equipment									X	X	
Cut Away Damaged Structure	X								X	X	
Bend Metal	X								X	X	

CREWMAN EVA TASKS

EVA construction and payload use tasks can also be grouped into two basic categories of crewman-oriented tasks, as shown on the following page.

- Using tools to perform manual operations

- Positioning and manipulating objects of various sizes

The following definitions apply throughout this report.

- Fabricate - Manufacture low density structure in orbit from high density bulk material launched from Earth.

- Assemble - Connect together in orbit previously manufactured elements.

- Deploy - Erect in orbit a previously folded or rolled structure.

- Small Object - Characteristic dimensions - Length $<.25$ m, or Mass $< .25$ kg.
  Crewman requires hand strength, finger dexterity or both.

- Medium-Size Object - $.15 \text{ m} < \text{length} < 2 \text{ m}$, or $.25 \text{ kg} < \text{Mass} < 150 \text{ kg}$.
  Crewman uses one or both arms and upper body.

- Large Object - Length > 2 m, or mass > 150 kg.
  Crewman uses whole body forces.

TYPICAL CREWMAN EVA TASKS

- Use of Tools and Manual Operations
  - Cut/Trim
  - Make Holes
  - Install Mechanical Fasteners
  - Fasten by Welding or Fuse-Bonding
  - Use Alignment and Checkout Equipment
  - Remove/Install Access Panels
  - Clean/Service
  - Replenish Expendables
- Position and Manipulate Objects
  - Manipulate Small Objects
  - Position Medium and Large Structure Elements

RANGE OF EVA TASKS

To summarize the range of crewman-oriented tasks relative to the payload tasks, the maximum and minimum EVA tasks were identified.

These tasks were analyzed to identify EVA performance requirements, as discussed in the following section of this report.

SUMMARY OF RANGE OF IDENTIFIED EVA TASKS

Task		Position	Fabricate/Assemble	Activate/Maintain/Repair
		Representative Operations		
Manipulate Small Object – Hand Strength, Finger Dexterity	Max.	Install Screw Jack Fittings.	Use Hand Tool.	Replace ACS Thruster
	Min.		Connect Cable Fitting.	Mate/Demate Connector
Position Medium-Size Object – Use One or Both Arms & Upper Body	Max.	Position Cable Reel.	Install Rotary Joint.	Replace Electronics Pkg.
	Min.	Install Beam Struts.	Install Electronics Pkg.	Position Fluid Resupply Bottle.
Position Large Object – Use Whole Body Forces	Max.	Position Cargo Pallet.	Position Composites Fabrication Module.	Replace Solar Array Blanket
	Min.	Rescue EVA "buddy".	Erect EVA Scaffolding.	Position Replacement RF Panel.
Cut/Trim	Max.		Cut 1m Beam Cap/Tube	Cut Away Damaged Area.
	Min.		Trim Fluid Tube	Splice Wire/Trim Insulation.
Make Holes (Drill, Ream, Punch)	–		Punch Cable Clamp Holes	Punch-Rivet Beam Splice.
Fasten-Mechanical (Separate Fasteners)	Max.		Attach Antenna Gimbal to Frame.	Replace ACS Pod.
	Min.		Attach Strut Fittings.	Replace Small Component.
Fasten-Weld/Fuse Bond	Max.		Weld Beam Cap Sections.	Repair Major Damage
	Min.		Fuse Struts to Longerons.	Repair Minor Damage
Align	Max.		Align Antenna Contour.	Align Replaced Section.
	Min.		Check Beam Cap Straightness.	Align Thruster/Sensor.
Checkout	Max.		Inspect Assembly and Proof Parts.	Inspect Damage/Repair.
	Min.		Verify Tooling.	Trouble-shoot a Function.
Clean/Service	–		Clean Forming Rolls or Fusing Heads.	Clean Sensor Optics.
Replenish Fluids	Max.			Replenish Pressurants/Propellants.
	Min.			Replenish Lubricants.

POSITION LARGE OBJECTS

An issue in construction is man's ability to move large objects and position them accurately in zero-g. This issue was studied to indicate the feasibility for handling Shuttle payloads by manned EVA. Such payloads could be whole cargo pallets to be berthed to a structure or large structure subassemblies to be joined together.

As shown on the opposite page, NASA underwater zero-g testing has already shown that positioning of large objects "by hand" is feasible, and can be considered to be a usable method.

POSITION LARGE OBJECTS

- 3727 kg (8200 Lb) Objects Positioned in NASA-JSC Underwater Zero-G Simulation Tests
- Object Accurately Positioned Within 15 cm (6 In.)
- 2 Men Performed Task Easily, 1 Man Could Perform Task.
- Velocities Achieved — 0 to 0.15 m/sec (0 to 6 In/Sec)
- Forces of 132 to 178 N (30 to 40 Lb) Required.

<u>Conclusion</u>

Positioning Large Objects By EVA Is Feasible.

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REQUIREMENTS

Three groups of issues were identified and studied to define the broad ECWS requirements. The results of these issue studies are presented in this section.

- Task Complexity Considerations
  - Mobility and Strength
  - Skill
  - Task Frequency and Duration
  - Manpower Levels and Proximity
- Ancillary Equipment Requirements
  - Restraints
  - Lighting
  - Tools
- Performance Requirements Considerations
  - EVA Sortie Duration and Frequency
  - EVA Enclosure Gas Composition and Pressure
  - Radiation Issues
  - ECWS Metabolic Load Profile

The results of these studies were combined with vehicle and structure considerations into the ECWS Construction Guidelines and Requirements Document, which is included at the end of this section.

MOBILITY AND STRENGTH

Mobility and strength are concerned with the variety and range of motions, forces and torques required to perform the ECWS EVA tasks.

The accompanying joint motion table shows the range of motions identified to date, and compares them to nude body joint motion ranges.

The following points are significant:

- Finger dexterity and tactility will be required. However, due to the special problems of achieving dexterity and tactility in a low-force, pressurized glove, the ECWS mobility requirement will be defined as "best achievable" for the present time.

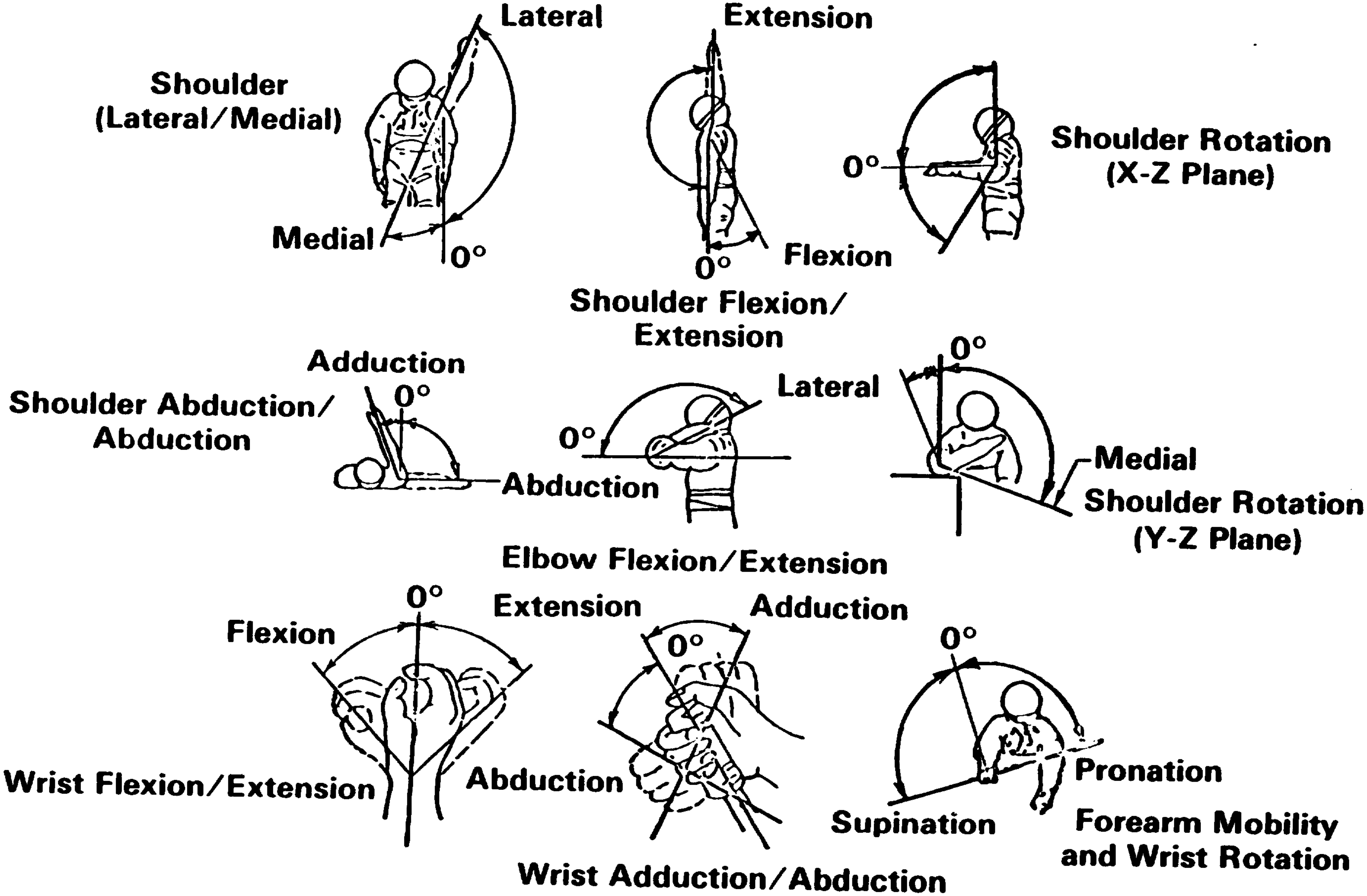
- Most EVA tasks require motion of just the hands, arms, shoulders and waist, providing that the body can be positioned for comfort, and articles of use are within reach.

- Lower body mobility, involving the hip, knee and ankle are important in orbit primarily positioning the body and large objects. In 1-g training, the ability to walk is required.

- If firm foot restraint is provided on an easily-adjusted worksite, the lower body can be rigidly encased, and the need for external hip, knee and ankle mobility can be eliminated for 0-g tasks performed in one location.

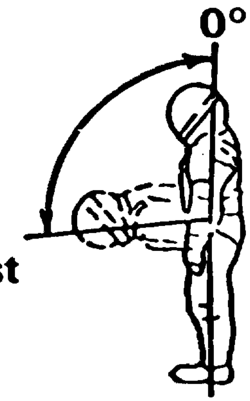
COMPARISON OF JOINT MOTIONS

Joint Motion	Nude (Degrees)	ECWS Motion Requirement (Degrees)
Shoulder — Lateral	180	150
Shoulder — Medial	40	20
Shoulder — Extension	188	180
Shoulder — Flexion	61	180
Shoulder Rotation — X-Z Plane	90	90
Shoulder Adduction	48	150
Shoulder Abduction	134	150
Shoulder — Y-Z Plane	34 Lateral 97 Medial	120
Elbow Flexion/Extension	142	130
Forearm Mobility — Supination	113	120
Forearm Mobility — Pronation	90	
Wrist Extension	99	90
Wrist Flexion	90	
Wrist Abduction	27	120
Wrist Adduction	47	
Wrist Rotation	180	180

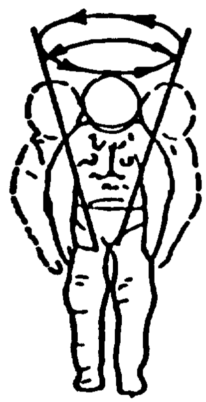

Lateral
Extension
Shoulder
(Lateral/Medial)
Medial
0°
0°
Flexion
Shoulder Flexion/
Extension
0°
Shoulder Rotation
(X-Z Plane)
Adduction
0°
Shoulder Abduction/
Abduction
0°
Abduction
Lateral
0°
Medial
Shoulder Rotation
(Y-Z Plane)
Elbow Flexion/Extension
0°
Extension
Adduction
Flexion
0°
0°
Wrist Flexion/Extension
Abduction
Pronation
Supination
Forearm Mobility
and Wrist Rotation
Wrist Adduction/Abduction

COMPARISON OF JOINT MOTIONS

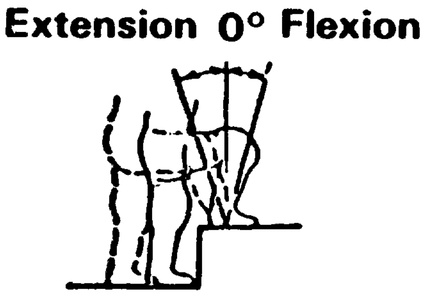
Joint Motion	Nude (Degrees)	ECWS Motion Requirement (Degrees)
Hip/Waist Flexion	90	75
Waist/Spine Mobility — Rotation	120	150
Ankle Flexion	35	40
Ankle Extension	38	40
Hip Flexion	113	70
Hip Abduction	45	10
Knee Mobility (Standing Flexion)	113	120
Knee Mobility (Forced Flexion)	159	150



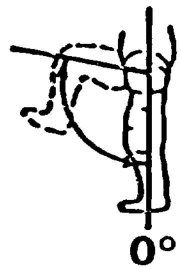
Hip/Waist Flexion



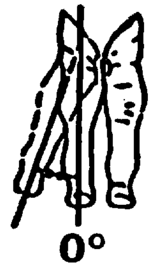
Waist/Spine Rotation



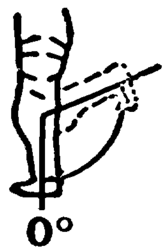
Ankle Flexion/Extension



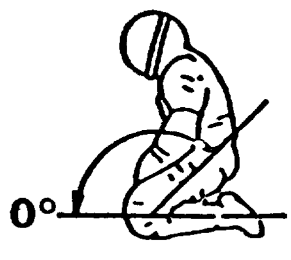
Hip Flexion



Hip Abduction



Knee Mobility (Standing Flexion)



Knee Mobility (Forced Flexion)

FORCES AND TORQUES

The table below shows actual values of forces and torques required to perform Skylab tasks.

From these results and from underwater zero-g simulation tests, it is expected that typical ECWS EVA tasks will require the range of forces and torques shown in the table opposite.

SKYLAB FORCE EXPERIENCE

Open/close EVA hatch	200 N Max.
Open/close interior hatches	156 N Max.
Actuate hatch latches	110 N Max.
Open/close ATM access doors	44.5 N Max.
Latch/unlatch S052 latch handle	17.8 N Max.
Lock/unlock S052 latch lock tee handle	55.9 N Max.
Install ATM camera	44.5 N Max.
Overcome ATM S082 latch level detents	71.5 N Max.
Operate S082 latching handles	
a. sustained	80.4 N Max.
b. impulse	160 N Max.
Actuate S082 container locking mechanism	13.3 N Max.
Operate S082 container open-close level	66.7 N Max.
Open S082 container lid	35.6 N Max.
Actuate S056 trigger mechanism (hand squeeze)	149 N Max.

SKYLAB TORQUE EXPERIENCE

Lever Type Controls

Control lever	2.84 N Max.
	0.7 ± 0.5 N.m operating
Selector Valve	1.7 N.m
Flow Control Valve	1.7 N.m

SKYLAB CONNECTOR MATE/DEMATE TORQUE EXPERIENCE

Gas Fill	1.13 N.m Max.
Propellant Supply	3.40 N.m
Electrical	4.08 N.m Max.
	0.80 N.m Min.

ECWS TASK FORCES AND TORQUES

● Two-Arm Push/Pull	200N (45 Lb)
● Whole-Body Push/Pull-Raise/Lower	200N (45 Lb)
● One-Arm Push/Pull-Raise/Lower	
Impulse	160N (36 Lb)
Sustain	110N (25 Lb)
● One-Arm Torque — Whole Arm and Shoulder	5 m-kg (36 Ft-Lb)
● Forearm Torque — Wrist	0.06 m-kg (4.5 Ft-Lb)
● Hand Grip	150N (34 Lb)

TASK SKILL LEVEL REQUIREMENTS

Skill levels are defined below relative to the susceptibility to damage of the equipment or work piece and the degree of difficulty of the operation being performed. Because space construction requires a range of tasks comparable to airframe assembly, structural steel erection, and electrical and machinery maintenance trades, workers with specific skills in all of these areas will be required. Furthermore, due to the small size of EVA work crews (2 to 4), each worker must be knowledgeable in all of these fields.

SKILL LEVELS

	LOW	MODERATE	HIGH
Equipment/Work Piece	Difficult to abuse Repairable in orbit	Damagable by abuse Not repairable in orbit	Damagable by normal handling
Operation	Force on motion limits cannot be knowingly exceeded	Damage if force or motion limits are exceeded	Requires delicate touch or precise set-up Requires eye coordination with force or motion feedback

In addition, each worker must be a craftsman in these fields. Due to the high cost of EVA support (projected to be on the order of $10K to $20K/man-hour) tasks must be done quickly, yet correctly the first time.

Since like the air and the sea, the EVA work environment is unforgiving, each worker must also possess a thorough practical knowledge of his ECWS. He must understand his physiological and equipment limitations so that he will not over extend the combined capability of man and support equipment. He must also fully understand the hazards of the work place so that he will not take unnecessary changes that would endanger himself.

TASK SKILL LEVEL REQUIREMENTS

Task	Operation	Low	Moderate	High
Cut/Trim	Cut Beam	X		
	Splice Electrical Wiring			X
Make Holes	Use Guided Set Up	X		
	Freehand Drilling/Punching		X	
Fasten-Mech.	Fasten Prealigned Parts.		X	
	Install Component		X	
Fasten-Weld/ Fuse-Bond	Freehand Repair Welding			X
	Fusion-Bond Parts		X	
Align	Perform Alignment Using Hand Tools			X
	Set Up Alignment Equipment		X	
Checkout	Inspection	X		
	Troubleshooting		X	
Clean/Service	Machinery	X		
	Optics		X	
Replenish Fluids	Propellants/Pressurants		X	
	Lubricants		X	
Manipulate Small Object	Structural Tooling	X		
	Use Hand Tools		X	
	Mate-Demate Connector		X	
Position Medium Size Object	Position Lable Reel		X	
	Structure Fabrication/Assy.		X	
	Replace Electronics Assembly Pkg			
Positon Large Object	Apply Steady Force for Several Seconds to Accelerate/ Decelerate Cargo Pallet		X	
	Rescue EVA "Buddy"		X	

TASK DURATION AND FREQUENCY

Consideration of the tasks shows that many short duration tasks associated with erection of structure have potential for being repeated a great many times. These tasks should be considered as candidates for some degree of automation, if high repetition occurs at a single location, or at least should merit some special tooling to reduce labor content.

Other task types associated with activation and maintenance will be relatively unpredictable in duration, and will be performed relatively infrequently. Special equipment is expected to be required to enable the task to be performed properly, safely and with minimum labor content.

Welding/fuse bonding is a special case. Beam fabrication is expected to require extensive fixed head welding or bonding. However, when performed by hand, welding is a high-skill operation. Therefore to minimize the requirement for high skill man-hours, fixed-head welding/fuse bonding should be automated.

The locale for repair welding will be random, and therefore is not amenable to a fixed head process. Of necessity, this work would be performed with portable, handheld equipment.

TASK DURATION AND FREQUENCY

Task	Duration	Frequency	
Cuts	4 to 10 Minutes	Hundreds	Candidate for Automation
Holes	1 to 2 Minutes	Thousands	Candidate for Automation
Fasten-Mech.	3 to 5 Minutes	Thousands	Candidate for Automation
Fasten-Weld/ Fuse Bond	10-30 Minutes 2-10 Minutes	Km of Seams Hundreds of Joints	Automate All But Repair Welding
Align	Variable	Tens	As Required
Checkout	Variable	Tens	As Required
Clean/Service	Variable	Hundreds	As Required
Replenish Fluids	Variable	Tens	As Required

ECWS TASK MANPOWER LEVELS AND PROXIMITIES

The ECWS EVA tasks thus far identified appear to be best accomplished with relatively few people. With EVA crews expected to number 2-4 people several tasks may be carried on in parallel.

Most task types can be accomplished by one person.

Alignment and checkout, which can occur over long distances, can use several people in a team effort, with various members making adjustments or using instruments.

Positioning of large objects and assembly of beam sections can also use several crew members working together over moderate to long distances.

Task	No. and Proximity of Crewmen Required	
Cut/Trim	1-2	1 to 2m
Make Holes	1	N/A
Fasten-Mechanical section	1-2	Up to 250m for fastening a beam
Fasten-Weld/Fuse Bond	1	N/A
Align	1-3	Up to 250m for SPS test article
Checkout	1-4	Up to 250m for wire-run trouble-shooting
Clean/Service	1-3	2 to 3m for machine service.
Replenish Fluids	1	N/A
Manipulate Small Object	1	N/A
Manipulate Moderate Size Object	1	N/A
Position Large Object	1-2	Up to 20m for cargo pallet

RESTRAINTS

CREWMEN

For crew translation hand holds and tether attachment points must be provided.

For one-handed manipulation of small objects the crewmen must be tethered and have one hand hold.

For all ECWS tasks involving two-handed tasks or moving moderate or large size objects foot restraints must be provided.

The restraints should be capable of being repositioned to permit EVA crewman to adjust their location for comfort. This is particularly true for EVA tasks requiring the crewmen to remain in one location for long periods of time.

TOOLS AND SMALL OBJECTS

Small tools and loose parts should have tether attachment or capture means to keep them from drifting.

MEDIUM AND LARGE OBJECTS

Medium and large objects moved by mechanical means should be firmly attached to the effector on the mover. If positioned by crewman effort, the objects should be tethered to hard structure and not to the crewman.

LIGHTING

Lighting requirements fall into two general categories:

- General area lighting to illuminate regularly-used translation corridors or support repetitive tasks performed in one area, such as beam fabrication. This is fixed lighting.

- Local lighting to illuminate specific work site or work piece areas. This is portable lighting.

Intensities of both categories of lighting should be matched to the fineness of the task being performed, EVA color densities and to the contrast of the work area with the background. Typical intensity requirements are as shown on the opposite page.

The lighting environment consists of three general regimes.

- Full sunlight. Artificial lighting not required.

- Earth dark side. Artificial lighting is required.

- Structure dark side. Artificial lighting may be required depending upon reflection from adjacent structure.

It is expected that general lighting will be turned off 62% of the time when direct or reflected sunlight illuminates the work area with an adequate intensity for working. Local lighting may be required up to 100% of the time if the worksite is shadowed, or if contrast between light and shadow requires softening.

LIGHTING NEEDS

General Worksite — Fixed Area Illumination

— ≈ 36 Min Per Orbit (38% of Time) When SCB in Shadow

Local — Portable Work Piece Illumination

— May Be Required 100% of Time If Work Is Shadowed by SCB

Illumination Levels	Foot-Candles
Translation Corridor	1-20
General Worksite	30-200
Work Piece	
— Assembly	30-100
— Hand Tool Use	70-100
— Testing	50-200
— Inspection	100-200

TOOLS

Apollo and Skylab experience showed that with adequate body restraint an EVA astronaut could work effectively with simple hand tools. Torque-cancelling features were not required. Hence, the ECWS Study Program Approach is to identify tool characteristics in terms of modifications to 1-g tool concepts.

The list of tool types on the opposite page contains special and general purpose tools required to perform the ECWS EVA tasks. It is expected that tool types will resemble their earthbound counterparts except in the following areas:

ECWS TOOL CHARACTERISTICS

- Will not overheat in vacuum
- Withstand space environment
- No-glare reflection
- Contain debris control
- Improved safety guarding
- Compatible with guide fixturing
- Tetherable/capturable
- Compatible with gloved hand or end effector
- Provisions for local lighting
- EMC compatible
- DC operation
- Minimal handling of individual tool bits and drivers

Task	ECWS Tool Types
Cut/Trim	Cutting Tool (Saw, File, Shear) Tool Guide (Miter Box) Debris Control
Make Holes	Drilling Tool (Drill, Ream, Hole Saw, Punch) Debris Control
Fasten-Mechanical	Clamp, Wrench, Riveting Tool, Pin Expansion Tool
Fasten-Weld/Fuse Bond	Weld (Electron Beam, Spot, Seam) Fuse (Induction Heat Coil)
Align	Alignment Tools (Snap Lines, Measuring Rods, Optical Surveying Systems)
Checkout	Gages, Measuring Tapes Troubleshoot Instruments (VOM & Discontinuity Meters, Valve Actuating Handles, Leak Detection Gear)
Clean/Service	Cleaning Wipes, Lubrication Service Tools, Anti-Static Materials, Solvents, Scrapers, Brushes, Heat Gun
Replenish Fluids	Fluid Transfer Package (Fluid Supply Accumulator, Pressurant, Valves, Gages, Regulators, Hoses, Disconnects)
Manipulate Small Objects	Assorted Hand Tools

EVA SORTIE DURATION/FREQUENCY

Two distinct phases of construction operations have been identified, namely:

- Early ECWS use
- Late ECWS use

Early use is characterized by the building of the demonstration/test articles, probably using highly paid, highly skilled and highly motivated personnel. The work will be experimental because this activity will be largely unprecendented.

There are similarities in the work situation with present Shuttle EVA planning and with the recently completed construction of the Trans Alaska pipeline, whose characteristics are:

	Shuttle EVA	Pipeline
Sortie Length	7 Hours	6 Hours
Sorties/day	1	2
Sortie Repetition rate	Up to 6 in 7 days	7 day/week for 3 Weeks
Time without Sortie	Min. 2 weeks flights	7 day/week for 3 Weeks

Early ECWS EVA sortie requirements are expected to be as follows:

	Early ECWS Use
Sortie length	6-8 Hours
Sortie/day	1
Repetition rate	6 days/week for 30 to 180 days
Time without Sortie	6 months minimum between flights

EVA SORTIE DURATION/FREQUENCY (CONTINUED)

Late ECWS use is characterized by building of full scale structures, using hundreds to thousands of people. Work is expected to be more routine than during the early use period. This work has similarities with present land based construction activity and shipboard duty, whose characteristics are:

	Construction	Shipboard (Submarine)
Sortie Length	4 Hours	6 Hours
Sorties per day	2	1 per 18 hour day
Sortie Repetition rate	5-6 days/week	continuous
Time without Sortie	2 weeks/year plus holidays	1 to 6 months/year

Late ECWS EVA Sortie requirements are expected to be as follows:

Sortie Length	4-6 Hours
Sortie/day	1-2
Repetition rate	6 days/week for 180 days
Time without Sortie	6 months minimum between flights

Mission duration/frequency considerations drive the ECWS life requirements as follows:

In flight: 8 hrs/sortie x 154 sorties/flight = 1232 hours

10 missions, with ground maintenance between flights,
yields 10 year calendar life: 10 missions x 1232 hours/mission = 12,320 hours life

EVA ENCLOSURE PRESSURE AND GAS COMPOSITION

OBJECTIVE

To select an EVA enclosure pressure level and gas composition.

GOAL

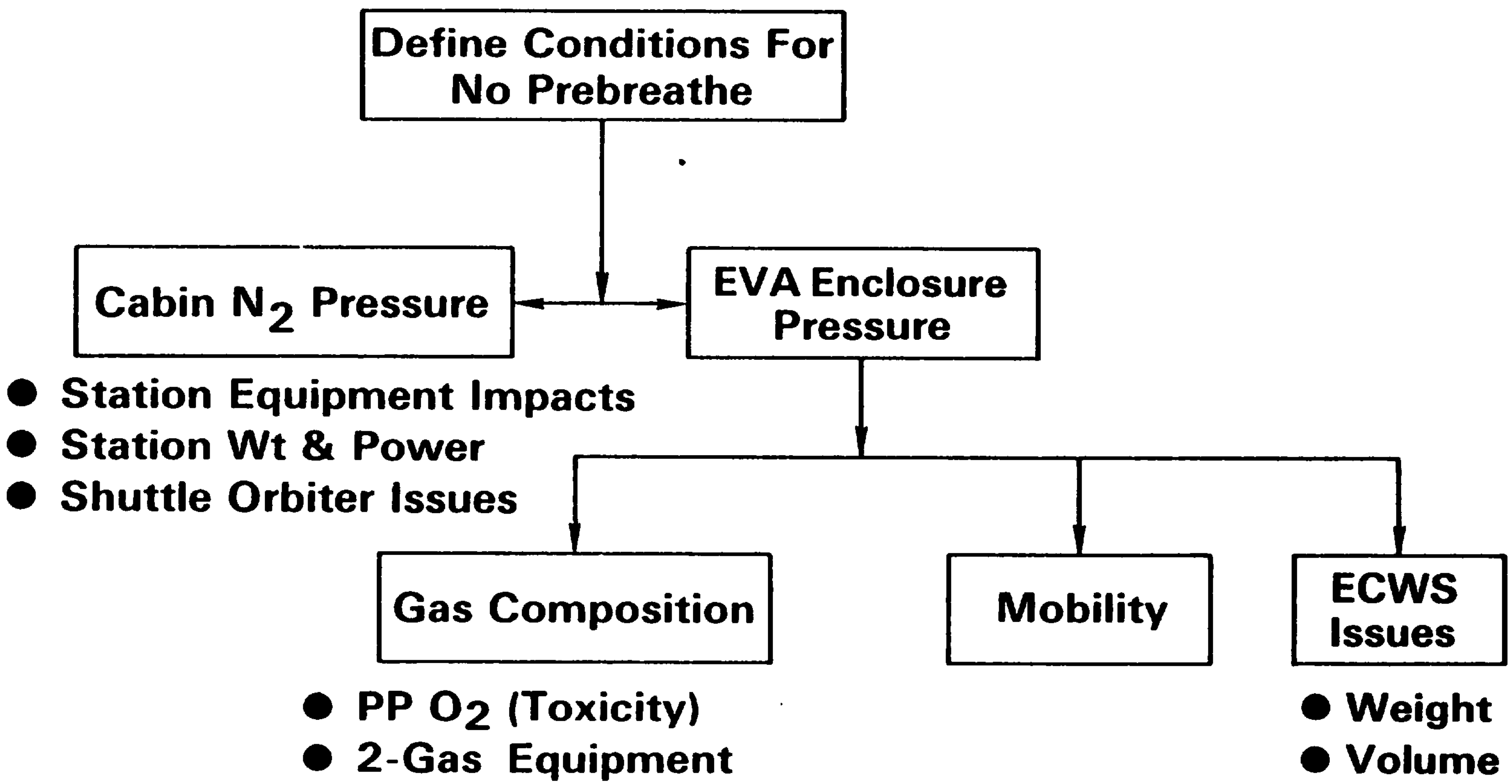
To eliminate the prebreathe requirement as indicated in the ECWS Study Guidelines.

APPROACH

To assess the issues and their interrelationships as shown, each area was studied separately for its impact on the total EVA enclosure pressure and gas composition questions.

The results of these investigations are discussed in turn as follows.

EVA ENCLOSURE PRESSURE LEVEL/GAS COMPOSITION ISSUES & INTERRELATIONSHIPS



CONDITIONS FOR NO PREBREATHE

Basic Considerations

Prebreathe (to avoid the "Bends") can be eliminated if the ratio P_{cabN_2} to $P_{suit} < 1.5$.

The ratio 1.5 is safe for tissues, including those poorly vascularized (slow) tissues such as bone and fat which require approximately 4 hours to purge one-half the dissolved N_2.

For ratios > 1.5 prebreathe time is required to halve "slow" tissue N_2 level.

Cabin Pressure Schedule

Based on minimum EVA enclosure pressure and nominal sea level O_2 partial pressure in the cabin, the schedule of maximum cabin total pressure bears the following relationship to nominal EVA enclosure pressure:

EVA Enclosure Pressure, psia		Cabin Pressure, psia	
Nom	Min	Max. PPN_2	Max. Pressure
4.1	4.0	6.0	9.0
5.0	4.9	7.3	10.3
6.0	5.9	8.8	11.8
8.0	7.8	11.7	14.7

EFFECT OF 8.8 PSIA VS 14.7 PSIA SCB CABIN PRESSURE

In considering 8.8 psia relative to 14.7 psia in a representative* SCB Cabin

ECLS Impacts

- Cooling fan weight and power increase to maintain system weight flows.

	Tended Modes	Perm. Manned
Weight Increase	11-20 Kg	31 Kg
Power Increase	3.7-6.8 Kw	4 Kw

- Vent flow fans stay at present cfm and weight while power decreases.

	Tended Modes	Perm. Manned
Power Decrease	.14-.27 Kw	.55 Kw

- There is no impact on heat exchanger, CO_2 Removal or Condensate Removal Subsystems.

N_2 Leakage

- Present 0.1" space vehicle wall thickness is good for 14.7 psia cabin.
- Wall thickness should not be reduced for lower P_{cab} due to LEO radiation protection requirements.
- Consideration of P_{cab} of 9.0 psia reduces N_2 leakage by approximately 50% and saves weight as follows:

	Tended Modes	Perm. Manned
N_2 tankage in SCB	173 to 206 Kg	477 Kg
N_2 tankage and gas resupply savings in Orbiter Payload	347 to 412 Kg	953 Kg

* Based on GAC SSSAS Configurations

SHUTTLE ORBITER ISSUES - OPERATION AT 9.0 PSIA

- With on-Orbit Avionics heat loads and present Orbiter ECLSS

	Avionics Bay Temperature °F			
	In	In Limit	Out	Out Limit
Electronic cooling stays within inlet and outlet temperature limits	82-91°F	100°F	83-124°F	130°F

	Cabin Temperature °F	
	Range	Range Limit
Cabin would exceed limit for periods of 2-3 hours per day. Potential solution would be a 2-speed cabin fan, with 60% increased flow capacity	70-92.6°F	70-77°F

- Potential Flammability

  - Sea level (3.1 psia) O_2 in 9.0 psia atmosphere is 35%. Allowable Shuttle limit is 30% O_2 with present materials.

  - Only 1 major material in Orbiter 101, TG 15,000 Silicon Fiberglas line insulation, failed at 35% O_2. This material is not available for S/N 102 and onward and will be replaced. The potential replacement would require evaluation at 35% O_2. Minor materials would also require assessment.

  - A potential workaround would be to reduce pp O_2 on on-Orbit to 30% of 9.0 psia, or 2.70 psia. This is equivalent to the O_2 partial pressure at approximately 4000 feet altitude, and does not appear to pose a problem to people who are conditioned to live at that altitude.

  - Vehicle impact would be to use a 2 schedule N_2 total pressure control and the possible addition of a 2 schedule O_2 partial pressure control.

  - Operational impact would be to bleed off approximately 40 lb of Shuttle atmosphere to reduce P_{cab} to 8.8 psia, at the proper 30% O_2 pp.

O_2 TOXICITY

Basic Considerations

There are levels of O_2 partial pressure above sea level (3.1 psia) which cause blood changes, tissue irritation and damage.

The O_2 toxic levels depend on

- Total Atmospheric
- Duration of Exposure
- Frequency of Exposure

The O_2 toxic levels have not been defined precisely.

Short Term Exposure

NASA has already accepted the following short term pure O_2 exposures for Shuttle Orbiter use, indicating that these exposures are permissible.

-	Prebreathe	3 hours at 14.7 psia
-	Rescue Ball	1 hour at 5 psia
-	EVA	7 hours at 4 psia with no medical constraint on EVA frequency

However, recent NASA sponsored tests* show blood changes and fatigue for intermittent exposure to:

- Pure O_2 at 8.0 psia for 8 hour/day for 14 days.

Long Term Exposure

Effects of excess O_2 occurred on

- Apollo at 5.0 psia pure O_2 for 14 days producing tissue irritation and blood changes.

- Skylab at 5.0 psia P_{tot} and 3.5 psia P_p O_2 for up to 84 days, producing blood changes.

Thus there is reluctance to allow long-term repetitious exposure to O_2 partial pressure levels significantly in excess of the sea level partial pressure. Hence, it is recommended that the maximum nominal O_2 partial pressure for EVA remain at 4.0 psia for the present.

*Reference - Report No. NADC 74141-40 "Physiological Responses to Intermittent Oxygen and Exercise Exposures", E. Hendler, Crew Systems Department NADC, Warminster, PA, 21 November 1974

MAINTAINING EVA ENCLOSURE GAS COMPOSITION

Analysis of current Shuttle EMU suit construction shows that after 8 hours, N_2 leakage would be sufficiently low to limit pp O_2 to approximately 3.6 psia at 5 psia total and approximately 5.5 psia O_2 at 8 psia total. On this basis, 2 gas control is not required.

Since cabin atmosphere and ECWS enclosure atmosphere composition would differ, it would be necessary to purge the EVA enclosure at donning. Purge time would be expected to be approximately 6 to 9 minutes. Purge equipment penalty for gas mixture would be expected to be a minimum of 34 Kg (75 lb) and a maximum of 53 Kg (116 lb).

EVA ENCLOSURE MOBILITY

The 4 psi suit technology appears to have adequate mobility for ECWS use. Inquiry centered on whether an 8 psig EVA enclosure can possess adequate mobility.

The primary concerns are:

- Shoulder/elbow/wrist/finger mobility
- Manual dexterity/tactility
- Comfort for repeated use over long time periods
- Durability over long time periods with high joint cycle life.

It was found that many concepts have already demonstrated at 8 to 14.7 psig operation is achievable. However, flight development costs will require expenditure to being such an EVA enclosure capability to operational status.

Examples are:

1972 - Apollo A7LB and Litton/Garrett Advanced Extravehicular Suits were evaluated at 8 psig by ILC.

1973 - NASA/Ames and Aerotherm demonstrated mobile, long life 8 psig glove.

1975 - Shuttle EMU SSA designed for 8 psig. However, it is currently being developed at 4 psig.

1975 - NASA/Ames demonstrated "Hard Suit" Concept.

Issues reduces to developing a flight EVA enclosure for 8 psi versus 4 psi operation.

ECWS ISSUES

Comparing potential ECWS Life Support System concepts for operation at 4 psia and 8 psia shows that at 8 psia:

- Leakage doubles, requiring approximately 5% more breathing gas,
- Power increases, requiring larger fan motors that draw additional 13 watts, and larger power sources that weigh an additional 1.14 Kg (2.5 lb) and occupy an additional 1065 cm^3 (65 in^3).
- Emergency gas supply systems would require twice the gas to maintain enclosure pressure for comparable durations with comparable leak sizes. Weight would increase 4.54 Kg (10 lb) and volume would increase by 3277 cm^3 (200 in^3).

These factors would significantly increase the weight and volume of an 8 psia ECWS LSS as compared to a 4 psia ECWS LSS increasing weight by approximately 5.68 KG (12.5 lb) and increasing volume by approximately 4342 cm^3 (265 in^3).

EVALUATION

To evaluate the EVA enclosure pressure and gas composition issues, the sensitivity of each issue to EVA enclosure pressure was identified. This process identified those issues which were significant in choosing EVA enclosure pressure.

Selection Issue	Issue Sensitivity to 4 vs 8 Psia EVA Enclosure	Is Issue Significant in Choosing Pressure?
P_pO_2	None	No
Gas Composition	Purge gas may or may not contain N_2	No
Purge Penalties		
Purge Time	3 Minutes	No
Purge Weight	19 Kg	No
Mobility	May require flight hardware developmenc program, including glove	Yes
Cabin Pressure	Could be 8.8 or 14.7 psia	Yes
Resupply Weight	May vary as much as 953 Kg/launch	Yes
N_2 Tankage Volume	May vary as much as 50%	Yes
Shuttle Issues	Assess low-use materials	Yes
	Assess cabin temperature and pressure control	Yes
	Assess one large-use material	Yes
ECWS Issues	Breathing gas volume may increase by 5%	No
	Emergency gas supply may increase by 4.54 Kg and 3277 cm^3	Yes
	Battery may increase by 1.14 Kg and 1065 cm^3	Yes

As shown overleaf, the issues favor the 4 psia EVA enclosure.

SUMMARY OF STUDY RESULTS

In conclusion, the recommended ECWS EVA enclosure gas is pure O_2 at 4.1 psia, using a vehicle cabin pressure of 9.0 psia. The ramifications of this recommendation are:

- Prebreathe can be eliminated
- Vehicle weight and resupply cost can be saved

NOTE: The EVA enclosure pressure will be restudied in the near future to determine how prebreathe can be eliminated from the existing Orbiter - EMU system. This study will address EVA from the Orbiter in support of vehicle inspection and repair, satellite and payload service and construction. The study will also consider potential impacts to Spacelab: thermal performance, flammability and effects on experiments.

RADIATION ISSUES

4 Sources of Radiation

- Solar Flares
- Galactic Cosmic Particles
- Trapped Solar Electrons & Protons (2 Van Allen Belts)
- Unscheduled Radiation Exposures

Radiation Exposure Limits Environmental Exposures

- LEO
- Transorbit — LEO to GEO
- GEO

SOLAR FLARES

Solar flares are high energy protons released during solar magnetic storms. They build up over several hours, and last for several days. Their occurrence cannot be forecast, but the onset of buildup can be detected. The statistical frequency of occurrence follows the 11 year solar activity cycle.

Solar flares pose a problem to habitation in GEO and at 55° LEO. A detection system will be required to warn of impending arrival. During a flare the crew will have to retreat to a heavy wall "biowell".

Flares have no access to 28 1/2° LEO, and therefore are not of concern to work in that orbit.

Hamilton Standard has been directed by NASA not to design the ECWS for operation during flares.

GALACTIC COSMIC PARTICLES

Galactic cosmic particles are omnidirectional particles from the stars. They possess very high energy, but very low flux density, and are virtually unshieldable.

The consist of:

- 87% Protons
- 12% Alpha Particles
- 1% Heavier Nuclei ranging from Lithium to Tin

The effect of these particles is expected to produce continuous low level radiation effect.

NASA has not included the effect of these particles in allowable radiation exposure limits, but it is probable that galactic cosmic particles will affect career limit values.

Hamilton Standard has been directed to use current NASA radiation exposure limits for the ECWS Study Program, as shown on page 4-41.

VAN ALLEN BELTS

The Earth is surrounded by a pair of concentric radiation belts consisting of electrons and protons. The belts result from the Earth's magnetic field trapping a portion of these particles that emanate from the sun as the "Solar Wind".

The belts are characterized as follows:

- The effects of the belts are manifest from approximately 300 KM to 55,000 KM altitudes.

- They are symmetrical with respect to the magnetic equator which is offset from the geographic equator by approximately 10°.

- The intensity of radiation is characterized both by flux (particles/sec-m^2) and by energy level (mev). Contours of energy level are indicated in the illustration.

- The 400 to 500 KM LEO environment is characterized by electrons and protons.

  Model Used -

Electrons	AE-5 solar Min. (Most Severe)
Protons	NASA SP-3024, Vol. 5 and 6, with Vol. 5 extended to 50 Mev.

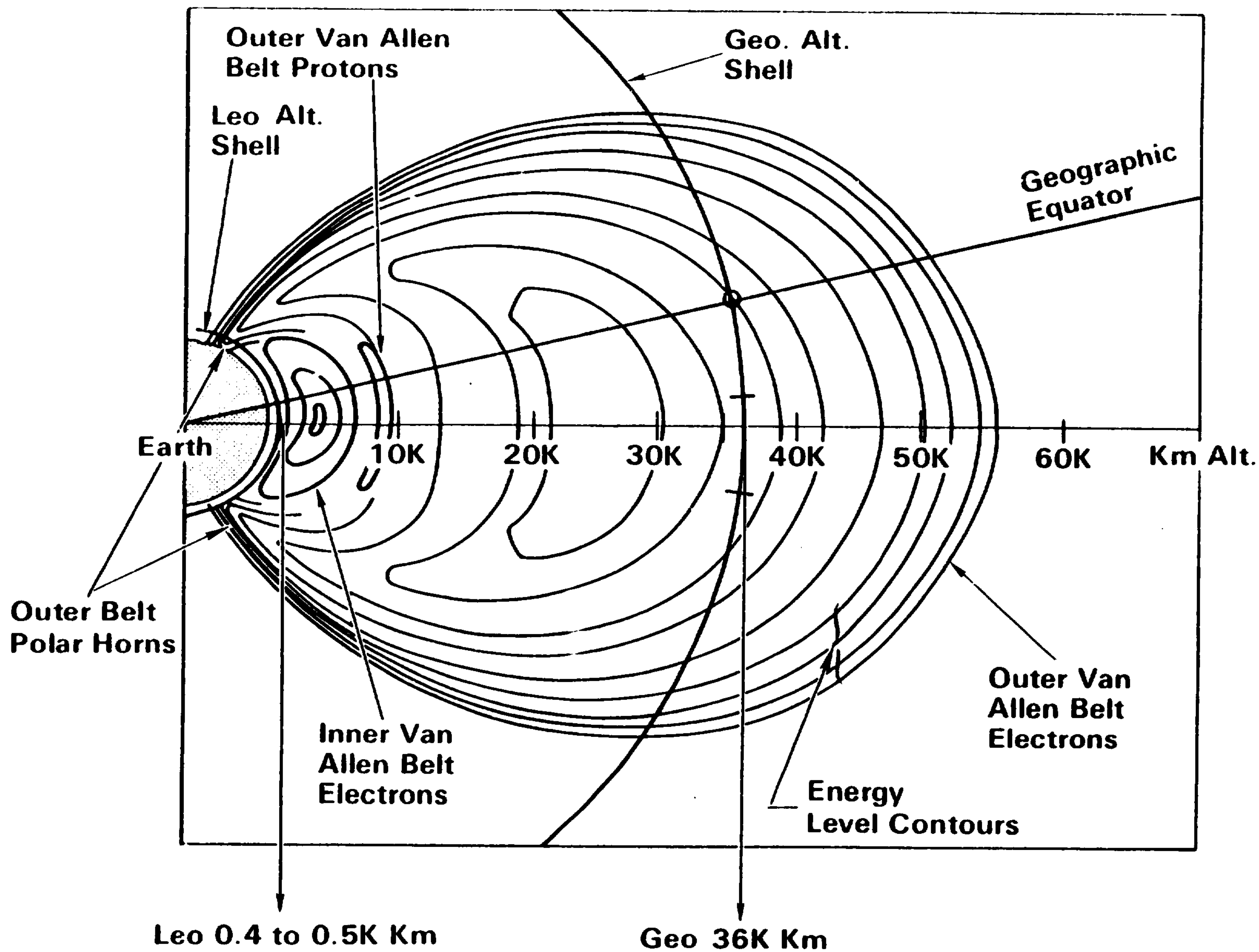
- In the Geo environment, at 36,000 KM altitude, protons are present, but are low level, and present no problem. Electrons are present at high energy. Their intensity varies by factor of 10 between local noon and local midnight, but this diurnal variation is most often masked by random magnetic disturbances.

  Model Used -

  Electrons AE-7 Hi (Most Severe).

  Time averaged to include diurnal variation and random storms.

VAN ALLEN BELTS



UNSCHEDULED RADIATION EXPOSURES

Unscheduled radiation exposures consist of exposure to potential on-board nuclear-powered payloads and equipment, as well as radiation doses received during unscheduled or emergency EVA, or exposure to solar flare radiation if work is being performed in orbits other than 28 1/2° LEO.

To account for the presence of on-board radiation sources and for unplanned exposure to radiation, NASA has recommended that only 60% of NASA Exposure Limits for Trapped Solar Electrons and Protons be used for normal exposure and for planning scheduled EVA activities.

This strategy leaves 40% of the exposure limits available to cover unscheduled radiation exposures.

RADIATION BIOLOGY ISSUES

NASA radiation exposure limits, presented overleaf, are expressed in REM (Roentgon-Equivalent Man). One REM is defined as the amount of radiation that produces the same radiation effect in human tissue as one Roentgon of X-rays. For reference, the following radiation doses are associated with typical radiation exposures:

Dental and Diagnostic X-ray	1-5 REM
Single whole body dose for the threshold of statistical shortening of life	200 REM
Single whole body dose producing death within hours	5,000 REM
Local dose accumulated over several weeks for tumor therapy	10,000 REM

Due to the spectral nature of the radiation environment, the intensity of radiation exposure, as it affects human tissue, varies with the orbit. In LEO low energy electrons and protons predominate. Since skin is an effective shield for the deeper tissues, skin exposure dose limits determine the required amount of radiation protection. In the transorbit regime and at GEO the radiation spectrum contains a much higher number of high energy electrons for which skin is a relatively poor shield. Radiation protection requirements here are driven by limit doses to the eye, followed closely by limit doses to the red blood-forming organs.

The limits shown in the table opposite are the current NASA-recommended exposure limits.* ECWS is using the 90 day limits taken for two consecutive quarters to cover the 180 day projected crew rotation.

The analysis to follow uses the 60% factor to build contingency for unplanned, or emergency EVA.

*Source: NASA/JSC Memo SD4-57-77, "Guidelines and Criteria for Radiation Analysis" J. V. Bailey, March 3, 1977.

RADIATION EXPOSURE LIMITS — REM

	30 Day	90 Day*	Yearly	Career
Skin	65	105	225	1200
Red BFO	25	35	75	400
Eye Lens	37	52	112	600

90 Day Limits Taken Twice Are Consistent with Plan to Rotate SCB Crew Every 180 Days.

ECWS Design to 60% of Above Levels to Provide for Exposure During Unscheduled EVA or to On Board Radiation Sources.

*Exposure to 2 Consecutive Quarters is Permissible Provided That No Further Exposure Causes Exceedance of Yearly Limits.

RADIATION IN LEO DEPENDS ON ORBIT TRACK

The Inner Belt dips close to the Earth in the region of the South Atlantic (centered at 35° West Longitude, 35° South Latitude), giving rise to the "South Atlantic Anomaly" (SAA). Within the SAA electrons and protons dip close enough to the Earth to irradiate a vehicle in a 400 to 500 KM LEO orbit during portions of orbit tracks over that region of the Earth.

The Outer Belt dips close enough to the Earth in the region of both magnetic poles, so that a vehicle in a 400 to 500 KM high inclination LEO orbit, such as 55°, will be irradiated during those portions of the orbit tracks in the vicinity of the poles.

The following points are significant:

- Irradiation is limited to discreet portions of the LEO orbit tracks that take a vehicle through either the polar horns or the SAA. Irradiation does not occur during other portions of those orbit tracks.

- All 28 1/2° LEO orbit tracks miss the polar horns entirely.

- Thus for the majority of a 24 hour period there is no radiation exposure in the 28 1/2° LEO orbits.

- Likewise most 55° LEO orbit tracks in a 24 hour period miss the SAA entirely.

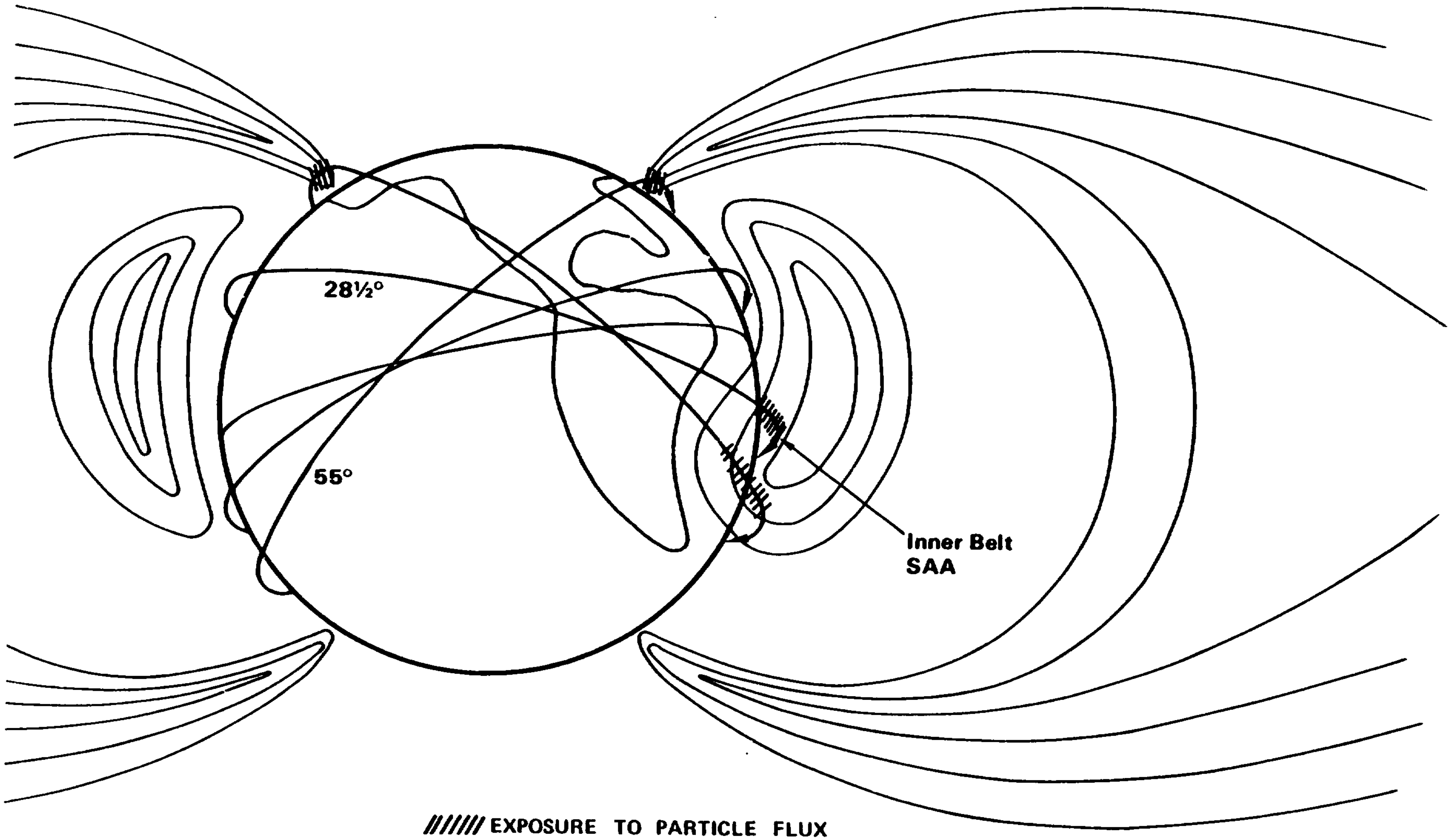
- But most 55° LEO orbit tracks pass through the polar horns from 1 to 4 times per revolution.

- Thus radiation exposure is a consideration on almost all 55° orbit tracks, although exposure will vary with passage through the SAA and/or polar horns.

- Since irradiation occurs only during that portion of an orbit track within the SAA or polar horns, a time plot of radiation intensity as the SCB proceeds along an orbit track, will show narrow "spikes" of radiation interspaced with time periods of zero radiation.

- These spikes show increased intensity as orbital altitude increases, since the orbit track passes through higher intensity regions of the polar horns and/or SAA.

RADIATION IN LEO DEPENDS ON ORBIT TRACK



////// EXPOSURE TO PARTICLE FLUX

LEO ENVIRONMENT

In any LEO Orbit during the course of a 24 hour day the SCB will pass through protions of the SAA and/or polar horns of the Van Allen Belts. Each exposure lasts just a few minutes out of any single 90 minute orbital revolution. Thus a time plot of radiation intensity will exhibit a characteristic of individual spikes, the height of each spike representing the intensity of the exposure experienced for a few minutes. On a 24 hour time scale the width of each spike is insignificant.

Representative peak values for radiation doses received as spikes by exposure in a suit of Shuttle EMU Construction are:

	28 1/2°	55°
400 KM	0.22 REM Skin	0.82
500 KM	1.9	2.8

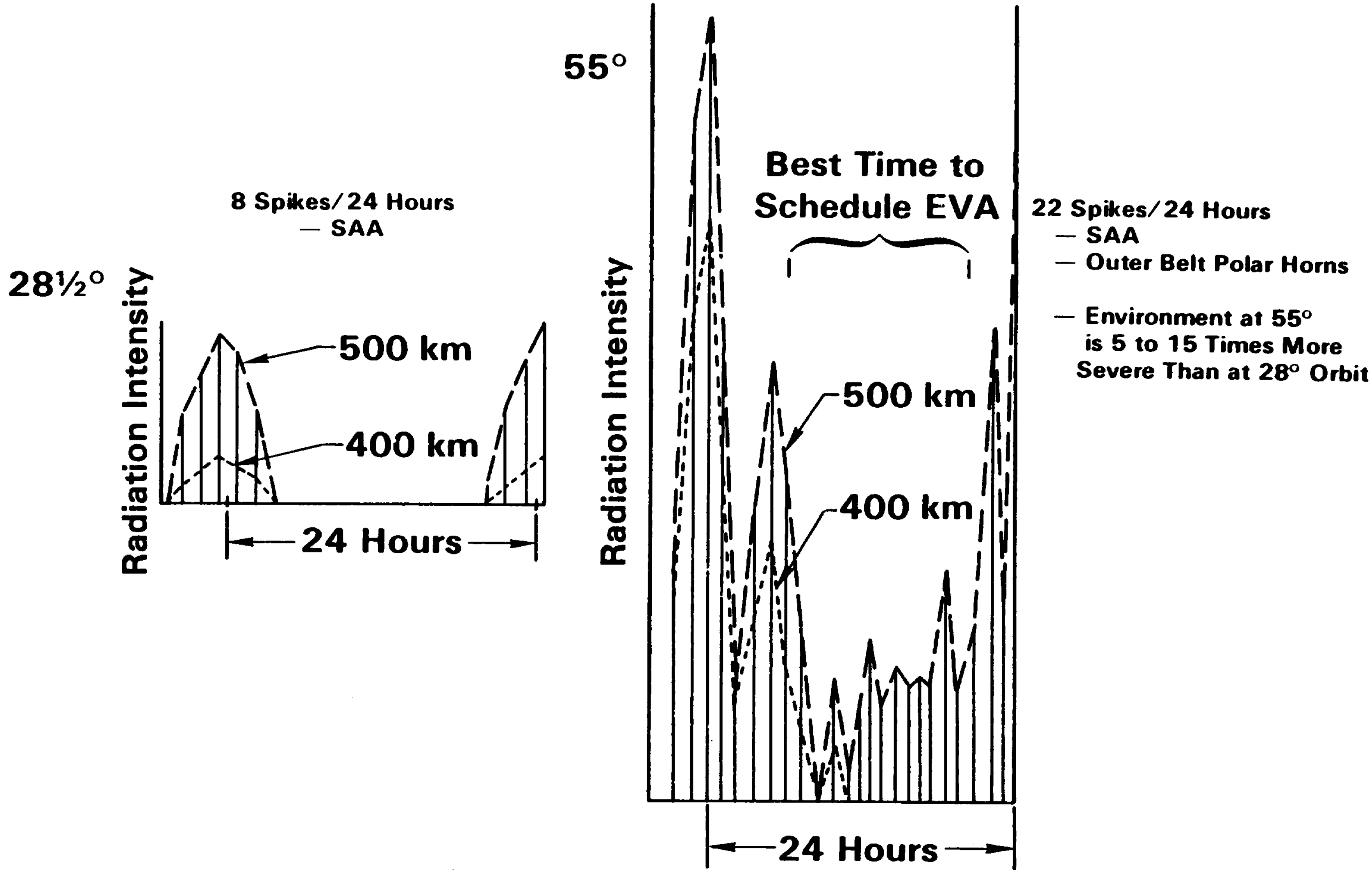
Representative total doses received in that suit construction for 24 hours are:

	28 1/2°	55°
400 KM	0.7 REM/Day	10.0
500 KM	3.0	16.4

Thus the effects of radiation environment at 55° is approximately 5 to 15 times more severe than at 28 1/2°.

If we consider the locus of intensity peaks, we see that there are periods within a 24 hour day when, for hours, only relatively low intensity radiation is received. These periods represent the best time to schedule EVA.

LEO ENVIRONMENT



LEO - SCHEDULED EVA

Dose limit for scheduled activity is 60% x 105 REM = 63 $\frac{\text{REM}}{\text{Quarter}}$ for skin

The following exposures are based on equivalent Shuttle EMU soft goods (arms and legs) construction.

ORBIT		CABIN EQ. IN. Al		EXPOSURE, REM/Quarter					
				6 DAYS/WEEK			3 DAYS/WEEK		
				4 HR/DAY	6 HR/DAY	12 HR/DAY	4 HR/DAY	6 HR/DAY	12 HR/DAY
28 1/2°	400km	0.1 (Std. Space-craft)	Best	17.1	17.1	17.1	17.1	17.1	17.1
			Worst	45.8	50.0	55.9	31.5	33.7	36.6
	500	0.1	Best	55.5	55.5	55.5	55.5	55.5	55.5
			Worst	147	-	-	102	-	-
55°	400	0.2	Best	28.2	56.7	-	25.3	39.7	148
			Worst	399	-	-	213	-	-
	500	0.2	Best	63	109.2	-	52.5	75.4	-
			Worst	-	-	-	303	-	-

Doses in excess of 63 REM are not acceptable and require timing of EVA in orbit or selection of shorter EVA duration.

CONCLUSIONS

- In 28 1/2° 400km Orbit, Radiation does not limit EVA using Shuttle EMU and standard spacecraft thickness.
- EVA may be performed at other orbits, although timing in orbit becomes necessary, and consideration should be given to using a thicker spacecraft wall.

LEO SCHEDULED EVA

— Dose Limit for Scheduled Activity — 60% x 105 REM = 63 REM/Quarter for Skin

— Shuttle EMU Softgoods Construction and Standard Spacecraft Thickness

Orbit	6 Day/Week EVA Exposure	Exposure REM/Quarter	
28°-400 km	Worst 12 Hr/Day	55.9	⇐ Unrestricted EVA
500 km	Best 12 Hr/Day	55.9	

— Same Softgoods, Double Thickness Spacecraft

55°-400 km	Best 6 Hr/Day	56.7
500 km	Best 4 Hr/Day	63

LEO - UNSCHEDULED (EMERGENCY) EVA

Skin Exposure is Limit in LEO

Limit for Unscheduled EVA is 40% x 105 REM = 42 REM/Quarter

Equivalent Shuttle EMU construction - Exposure per unscheduled sortie and number of unscheduled sorties/quarter to produce a 42 REM exposure.

ORBIT		CABIN	DOSE/SORTIE AND NO. OF SORTIES		
		Thickness, Equiv. Inches of Al.	Worst 4 Hour Exposures	Worst 8 Hour Exposures	Av. 8 Hour Exposures
28 1/2°	400 KM	0.1 (Std S/C)	.51 REM/Sortie 82 Sorties	.61 REM/Sortie 69 Sorties	.31 REM/Sortie 135 Sorties
	500 KM	0.1	1.5 28	2.8 15	1.4 30
550	400 KM	0.2	5.0 8	5.9 7	3.8 11
	500 KM	0.2	6.9 6	8.8 5	5.5 8

Conclusion - Significant Contingency EVA Time Exists in LEO.

LEO — UNSCHEDULED EVA

- Dose Limit for Unscheduled Activity — 40% x 105 REM = 42 REM/Quarter for Skin
- Shuttle EMU Construction and Standard Spacecraft Thickness

Orbit	Worst 8 Hr. Exposure		Av. 8 Hr. Exposure	
	REM / Sortie	EVA Sorties	REM / Sortie	EVA Sorties
28½°-400 km	0.61	69	0.31	135
500 km	2.8	15	1.4	30
55°-400 km	5.9	7	3.8	11
500 km	8.8	5	5.5	8

TRANSORBIT LEO TO GEO

A chemical-fueled OTV can perform the Holman transfer ellipse from LEO to GEO in 5-1/4 hours. During that time the OTV will pass through the peak intensity regions of both Van Allen Belts. Since the transit time is relative slow compared with Apollo (hours vs minutes) the potential exposure is great, requiring a cabin wall density equivalent to 0.49 inches of aluminum to preserve 90% of the NASA recommended 90 day dose for the activities at GEO.

In such a vehicle the most severe round trip dose is 5.2 REM to the eye, representing 10% of the NASA-recommended 90 day dose. Concurrent with this would be a 5 REM exposure to the skin, representing 5% of the recommended 90 day dose and a 2.8 REM close to the red BFO, representing 8% of the recommended 90 day close.

An attractive alternative would be to reduce the vehicle wall thickness and have the crew don protective shielding for the transorbit trip. The following tabulation shows the vehicle thickness based upon round trip closage exposures of 10% of the recommended 90 day limits for both red BFO and skin, and shows how much body shielding is required by the crew.

10% Rd. Trip Dose		Equiv. Vehicle Thickness	Equivalent Additional Body Body Shield. Required, In. Al.		
Organ	Dose	In. Al.	Eyes	Skin	Red BFO
Red BFO	3.5	0.16	0.33	0.11	N/R
Skin	10.5	0.27	0.22	N/R	N/R

TRANSORBIT — LEO TO GEO

- 5¼ Hour Fast Transit — Hohman Transfer Ellipse
- Chemical OTV Stage
- Severe Environment — Hohman Transfer Ellipse Passes Thru High Intensity Regions of Inner & Outer Belts
- To Preserve 90% of NASA-Recommended 90-Day Dose, Requires Vehicle Wall or Crew Shielding

Limit	Vehicle Wall	Eye Shielding	Skin Shielding
Eyes	0.49 in Al	N/R	N/R
Skin	0.27	0.22	N/R
Red BFO	0.16	0.33	0.11

EVA AT GEO

EVA at GEO is TBD, but might reasonably be expected to range from short-term servicing to long term test supporting involving:

- Activation
- Checkout
- Maintenance
- Repair

Dose limit for scheduled activity is 60% (52 - 5.2) = 28.1 $\frac{\text{REM}}{\text{Quarter}}$ for Eyes where 5.1 REM is the round trip transorbit dose.

The following example is based on -

- Use of 4 inch thick GEO habitat.
- No preferred EVA time - EVA may be performed anytime.
- 8 hour EVA sortie

		EXPOSURE, REM/QUARTER			
EVA Enc. Eq. In. Al	Cabin Eq. In. Al	6 Day/Week	3 Day/Week	1 Day/4 Weeks	
0.277	4.0	27.9	18.9		
0.058	4.0			27.8	Equivalent to Shuttle EMU HUT/Helmet Construction

Conclusion

- A dense EVA enclosure is required for significant EVA work in GEO.

EVA AT GEO

Dose Limit for Scheduled Activity — 60% (52-5.2) = 28.1 REM for Eyes / Quarter

Trans Orbit Dose (5.2)

Cabin Thickness — 4 Inch Al Equivalent

EVA Enclosure Thickness for 8 Hour EVA Sortie

In. Al Equiv.	Frequency/90 Days	
0.277	6 Days/Week	
0.058	4 Hrs/4 Weeks	Equiv. Shuttle EMU Hut/Helmet

Conclusions — Dense EVA Enclosure Required for Regular EVA

RADIATION ENVIRONMENT CONCLUSIONS

The ECWS Study Program has shown that unrestricted LEO EVA time exists at 28 1/2° 400 km LEO using an EVA enclosure density equivalent to the present Shuttle EMU soft parts, namely 0.1 g/cm^2. Hence, it is recommended that this be the baseline requirement for the ECWS.

Additional radiation protection would be required to support unrestricted EVA in other LEO Orbits.

For GEO EVA substantial radiation protection is required, on the order of 0.277 equivalent inches of aluminum.

NOTE: Exposure to microwave radiation from structures or vehicles is an additional consideration. Unlike solar radiation microwaves are not ionizing radiation, but cause heating by interacting with water molecules within body tissues. Present U. S. industrial standards for permissible microwave exposure is 100 watts/square meter. Power density of microwave radiation at the antenna of a solar power satellite is expected to be on the order of 10,000 watts/square meter. Microwave power density may also be significant in the vicinity of vehicle communication antennas. Evaluation of power densities and their attenuation by helmet candidate materials is recommended for additional study.

ECWS METABOLIC PROFILE

ECWS metabolic profile was constructed using 2 EVA work models:

- High projected actual for performing heavy construction work
- Low projected actuals for performing light inspection and checkout

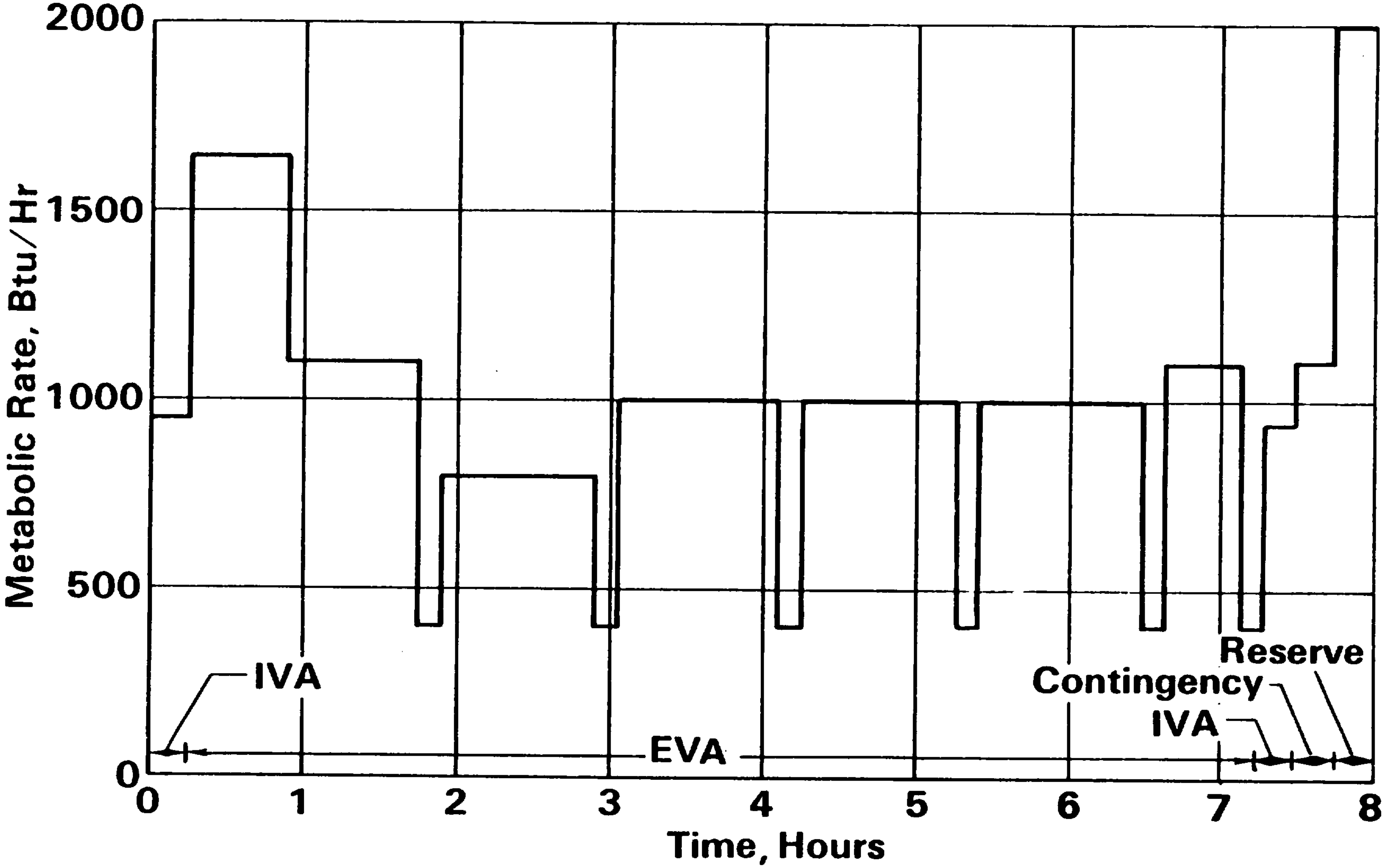
Metabolic values for the various ECWS tasks and sortie segments were estimated from actual Apollo and Skylab flight data as well as from NASA metabolic rate determination data.

COMPARISON OF METABOLIC RATES

		METABOLIC RATE (BTU/HR)			
MISSION AND DURATION		MIN	AVG	PEAK	TOTAL BTU
Apollo Trans Earth (1.37 Hrs)	Spec.	400	1200	2000	1640
	Actual	484	1080	1635	1480
Apollo Lunar (4 Hrs)	Spec.	400	1200	2000	4800
	Actual	488	913	1091	3652
Shuttle (7 Hrs)	Spec.	400	1000	1600*	7000
	Actual	-	-	-	-
ECWS (8 Hrs)	Spec.	400	1000	1650*	8000
	Hi Proj. Act.	400	1000	1650	8000
	Lo Proj. Act.	400	800	1100	6400

* In addition to 15 minute reserve at 2000 BTU/Hr.

ECWS, METABOLIC PROFILE SPECIFICATION



ECWS GUIDELINES AND REQUIREMENTS DOCUMENT

INTRODUCTION

These guidelines and requirements for the ECWS Study Program define the significant conditions under which the ECWS will be used. These guidelines and requirements result from two ECWS Study Program tasks - vehicle interface definition study and ECWS performance requirements study, combined with the results of past study and hardware programs.

This document is structured into two parts, namely:

ECWS Guidelines - defining vehicle and operational aspects affecting ECWS usage.

ECWS Requirements - defining performance and design requirements for ECWS system selection and preliminary design.

Subsequent program phases will evolve these ECWS guidelines and requirements into the ECWS system level specification, which will, in turn, guide the detailed design, development and certification of eventual flight hardware.

EVA GUIDELINES

General

- EVA will be a qualified operational capability for performing space structure construction, test, operation and maintenance/repair functions.

- EVA will be performed by EVA-trained personnel only.

- Construction crews will consist of two EVA construction workers, sometimes supported by a manipulator operator. For specific tasks EVA crew size may vary from two to four construction workers.

- Voice communications between members of an EVA team and the construction base will be available at all times.

EVA Sortie Planning

- EVA may be conducted during both orbital light and dark periods. Airlock ingress and egress may be performed during either period.

- EVA periods will not be constrained to ground-station coverage periods.

- During EVA days, EVA need not be constrained to specific daily periods. The ECWS should not limit the flexibility of mission planners.

- Prebreathing prior to EVA will not be required.

- Planned EVA sorties will be up to 8 hours duration.

- EVA workshift arrangement may be single shift or multishift.

- Some EVA tasks require only one crewman. EVA work should be scheduled to have two crewmembers performing EVA simultaneously.

EVA Safety

- No onboard, real time biomedical monitoring is contemplated.

- EVA crewmen shall not operate in or near a tumbling or uncontrolled structure or subassembly. Approaching unstable structure using a personal propulsion system shall be considered on an individual basis.

EVA Safety (Continued)

- Means will be provided to return a disabled EVA crewman to the airlock and to repressurize the airlock to a safe level within 30 minutes.

- If hazardous materials are to be handled during EVA, appropriate containers and/or transfer control devices should be provided to avoid direct exposure to the material.

Tethering and Restraint

- EVA crewmen and supporting equipment and materials will be tethered or restrained for all EVA tasks except those requiring use of a personal propulsion system or other free flyer. In such cases, the crewman and supporting equipment and materials will be secured to the free flyer.

- Planned free-floating EVA should be avoided and considered only on an individual basis.

- Structures should provide attachment points for EVA work stations, restraints and tethers at sites where potential EVA is anticipated.

- Crew translation tether or umbilicals should be managed in such a manner to preclude damage or entanglement and possible damage to surrounding equipment.

- All equipment transported or handled during EVA should provide a safety tether attach point.

EVA Translation

- Translation in close proximity to the construction base may be by hand rails, handholds, and/or with the crewman transported and supported on the end of the manipulator.

- Velocity for translation by handrail or manipulator will average 0.8 ft/sec. Peak speeds will be on the order of 2.0 ft/sec.

- Personal propulsion system translation will average 1.0 ft/sec.

- Crew translation using a manipulator as a cherry-picker is a potential utilization mode.

VEHICLE AND STRUCTURE GUIDELINES

Airlocks

- There will be an airlock integral to the Orbiter docking module and an airlock in the construction base through which construction workers will egress.

- Airlock repressurization time will be less than one minute. Rate will not exceed 1 psi/sec to preclude middle ear discomfort.

- ECWS Donning and Doffing may be done inside the airlock, but EVA enclosures will be stored outside the airlock.

Structure Features

- Structures should be designed to provide access to areas requiring the attention of EVA crewmen. The EVA crew transfer corridors and work site areas should be compatible with the size and mobility requirements of the EVA crewman and required support equipment.

- Structures should be designed to avoid sharp edges, corners and protrusions at work sites and along translation paths to avoid possible damage to the EVA enclosure.

  Representative values for finished structure should be typified by:

  Edge and In-plane Corner Radii   0.12 in. min.

  Exposed Edges, Radius or Smooth
  45° Chamber 0.06 in. min.

  Protrusions for Manipulation
  (switches, etc.) 0.06 in. max.

  Lap Joints and Plannar Mismatches 0.03 in. max.
  Mismatches to have radius or
  45° chamfer   0.06 in. min.

  Three-plane Corners Spherical welder or formed radii,
  unless protected by covers

Structure Features (Continued)

Rivet Heads	0.06 in. max.
Upset Rivet Ends	None in crewman access areas. 0.12 in. in exposed areas unless protected by covers
Bolt Heads	0.125 in. max. unless protected by covers
Exposed Threads	Protected by covers
Burrs shall be eliminated	Use of Allen head bolts preferred. Heads of slotted, torque set or Phillips head screws shall be taped or individually deburred

- Structures should be designed so that fabrication, assembly or deployment takes place while secured to the construction base.

- Structures should be designed to provide EVA crew safety from electrical, fluid, radiation, mechanical and other hazards.

- Structure equipment susceptible to damage if bumped during EVA should be protected or located out of the way of EVA translation corridors or EVA work site areas.

- Work areas and crewman interface provisions should be standardized as practicable to minimize development and training requirements.

- Structure equipment sensitive to EVA equipment effluent discharge should either possess inherent self-protective features, be provided with protectors to be installed by the EVA crewman, or have EVA crewman operational constraints defined. Specifically sensors cooled below 150°K should be shielded to prevent moisture condensation. Critical optical surfaces should be shielded to prevent static electric deposition of particles.

- Perturbing the structure or construction base attitude to satisfy lighting or thermal requirements of EVA should not be required.

- Planned EVA in the vicinity of construction base thrusters whose plumes could impinge on the EVA crewman should be avoided. If a contingency EVA is required in the vicinity, the thrusters should be inhibited.

- General area lighting will be provided at the work site and along EVA translation corridors.

ECWS REQUIREMENTS

The following requirements are established for use in the concept, tradeoff study and preliminary design phases of the ECWS program.

Reliability

- General life requirements of each of the ECWS shall be as follows:
  - Total number of nominal operation cycles - 10
  - Each nominal operation cycle shall consist of:

    154 sorties
    1232 operating hours
    6 months of calendar time

- Critical functions shall meet fail safe criteria. Fail safe is defined as suitable backup functions or redundancy to provide 30 minutes of ECWS contingency time.
- Manual overrides shall be provided on all critical automatic functions to permit safe operation during an emergency, e.g., pressure control.

Maintainability

- To support the reliability goal the following maintainability philosophy will be used.
  - Cycle life limited items such as pressure vessels will be replaced as required between operation cycles on the ground.
  - Limited life items that must be replaced during the course of one operation cycle (as exemplified by certain sensor types and batteries) will be replaced on a scheduled basis on orbit.
  - Provisioning several spare ECWS's is contemplated. In addition, sufficient select spare components will be provisioned on-orbit to maintain a rotable pool of ECWS's. Criteria for selecting the number and type of components to be provisioned will include:

Maintainability (Continued)

The predicted frequency of failure.
Ease of on-orbit replacement.
Ease of post-installation checkout on orbit.

- In addition to replacement of items and emergency repair, maintenance also consists of routine servicing, replenishment of expendables and checkout.

- Components requiring servicing or scheduled maintenance or predicted maintenance shall be accessible without the removal of other equipment, wire bundles, or fluid lines.

- Static and structural items shall be designed so that they require no on-orbit maintenance.

- The possibility of incorrect assembly, installation, and connections shall be eliminated by design.

- Attaching fasteners (except for captive screws and quick turn fasteners) should have two means for removal and must be accessible so that both means may be employed.

- Potting or adhesive requiring cure-processing shall be avoided in on-orbit maintenance operations.

- Electrical and fluid circuits requiring checkout or test points shall be so configured as to not require disconnecting fluid or electrical connectors which are connected during normal operation.

- The EVA enclosure design shall facilitate easy post-sortie wipe-down, drying and freshening.

Safety

- Safety is concerned with hazards to the crew and the spacecraft. The hazards to be considered are:

  Loss of EVA Enclosure pressure integrity
  Fire and explosion
  Performance failures
  Toxic materials
  Structural failures
  Micro-organisms
  Miscellaneous Hazards

- Replacement of components or modules shall be capable of being done without hazard to the crew, subsystems, or contamination to the cabin.

Safety (Continued)

- Where pressurized components could fail in such a way that a gas supply released would be greater than a relief valve or venting could handle without overpressurization, necessary flow restrictions shall be incorporated at the pressure source to restrict gas flow to a level that can be handled by the relief valve or venting. The flow restriction device must not interfere with the normal operation of the subsystem.

- Fluids which by themselves or which together with other materials could produce toxic or asphyxiant levels which would impair crew safety shall be kept external to the pressurized crew compartment.

- Materials shall meet requirements of MSCM 8080.

- Ignition sources shall be eliminated.

- EVA enclosure design shall recognize the hazard of potential contact with hard, sharp edges and abrasive surfaces, and shall incorporate means for reducing the hazard of pressure integrity loss resulting therefrom.

- The following factors of safety shall be used in the design of rigid structural components and parts.

- Means shall be provided for preventing violation of the ECWS pressure integrity while operating in a vacuum.

- Means shall be provided within the ECWS for signalling EVA crewman distress or disablement.

- Means shall be incorporated within the ECWS to permit attachment of a disabled EVA crewman to a rescue crewman or vehicle.

SAFETY

Item	Conditions	Factor of Safety	Remarks
General Structures	Combined worst conditions.	$\frac{2\sigma \text{ Strength Limit}}{\text{Stress}} \geq 1.5$	Strength limit is fatigue limit for dynamic conditions. Strength limit is yield strength for static conditions.
Amplification Factor		$\frac{\text{Response}}{\text{Input}} \geq 10.0$	
Cummulative Damage		$\frac{n_1}{N_1} + \frac{n_2}{N_2} \ldots \frac{n_n}{N_n} \leq 1.0$	n = number of cycles at a given stress N = number of cycles to failure at the given stress at $\overline{x} - 2$ with a factor of safety of 1.5 on stress
Hydraulic and Pneumatic Components	<u>Pressures</u> Liquids Proof Pressure	$\frac{\text{Proof Pressure}}{\text{Max Operating Press}} \pm 1.5$	
	Burst Pressure	$\frac{\text{Burst Pressure}}{\text{Max Operating Press}} = 2.0$	

SAFETY

Item	Conditions	Factor of Safety	Remarks
Hydraulic and Pneumatic Components (Continued)	Gases or liquids plus gases Proof Pressure	$\frac{\text{Proof Pressure}}{\text{Max Operating Press}} = 2.0$	
	Burst Pressure	$\frac{\text{Burst Pressure}}{\text{Max Operating Press}} = 4.0$	
	Structural Strength-stress based on proof pressure Strength-stress based on burst pressure	$\frac{\text{Yield Strength}}{\text{Stress}} \geq 1.1$ $\frac{\text{Ultimate Strength}}{\text{Stress}} \geq 1.2$	
Metal Tubing and Fittings	Max operating pressure	$\frac{\text{Ultimate Strength}}{\text{Stress}} \geq 4.0$ $\frac{\text{Yield Strength}}{\text{Stress}} \geq 2.0$	
Flexible Hosing	Max operating pressure	$\frac{\text{Ultimate Strength}}{\text{Stress}} \geq 4.0$	

Performance

- Life Support Subsystem Requirements

  The ECWS shall include a Life Support Section for use during normal operation and an emergency Oxygen Section for use during emergency operations. The LSS shall satisfy these requirements with the crewmember working at an average metabolic rate for a maximum duration of eight (8) hours. The ECWS shall be designed assuming an RQ and a metabolic rate as defined by Table 1.

- Breathing Oxygen Supply

  The LSS shall deliver oxygen for metabolic consumption, system leakage and pressurization as required. The supply oxygen shall be available for crewmember usage upon actuating a manual control.

  If recharge from the vehicle is required, the oxygen system will be compatible with vehicle supply pressures up to 3000 psig, which is the maximum operating pressure expected for an electrolytic oxygen generating system.

- Oxygen Pressure Control

  The LSS shall control the gas pressure level encompassing the crewmember's body during all operational modes.

- EVA Mode

  The LSS shall maintain the pressure within the Pressure Enclosure to 4.0 ± 0.2 psid with oxygen flows of 0.07 to 0.33 pound per hour and with ambient pressures from space vacuum to 14.9 psia.

- Vent Mode

  The LSS shall pressurize the Pressure Enclosure at 0.5 ± 0.1 psid with oxygen flows of 0.07 to 5.5 pounds per hour while operating in a pressure environment of 8.6 to 14.9 psia.

- Pressure Relief

  The system shall incorporate relief protection to prevent overpressurization of the pressure enclosure as a result of any single component or subsystem failure. The pressure level shall not exceed a maximum of TBD psid.

Performance (Continued)

- Temperature and Humidity Control

  Ventilating gas shall be recirculated, and shall enter the crewmember environment within the limits of 40°F to 90°F. There shall not be condensation of free water or helmet fogging and the dew point shall not exceed 65°F maximum at the pressure enclosure inlet. Absorbed moisture shall be removed from the ventilation flow.

- CO_2 Control

  The partial pressure of CO_2 entering in the crewmember's oral-nasal area shall not exceed 7.6 torr at metabolic rates up to and including 1650 BTU per hour and shall not exceed 15 torr at metabolic rates greater than 1650 BTU per hour during normal operation.

- Particulate Contamination

  The Contaminant control means shall limit particulate matter in the ventilating gas to 0.1 mg/m.

- Thermal Control

  The LSS shall provide sufficient thermal control capability to dissipate metabolic heat, inward environmental heat leakage and system generated heat. Thermal control shall be accomplished without reliance upon outward environmental heat leaks.

- Heat Storage

  The ECWS shall limit any required crewmember heat storage to $\pm$ 300 BTU.

- Emergency Life Support

  The ECWS shall supply 30 minutes of emergency life support at vacuum ambient after any single component failure, except catastrophic pressurization gas retention failure. This is compatible with return times of approximately 100 sec. from 300 m and 10 min. from 10 km distant from Orbiter.

- Metabolic Load Requirement

  The ECWS emergency life support provision shall be sized to support a metabolic load of 1000 BTU/hr and to provide this capability after pre-EVA checkout has been performed. The emergency life support capability shall automatically assume ECWS pressure regulation functions. Other emergency operating modes shall be selected manually.

Performance (Continued)

- Emergency CO_2 Control

  Following failure of primary ECWS O_2 circulation or CO_2 removal, the removal of CO_2 shall be accomplished by the Emergency Life Support provisions. The partial pressure of CO_2 entering the crewmember's oral-nasal area shall not exceed 15 torr under emergency conditions.

- Insuit Drinking Provisions

  The ECWS shall provide the crewman with a drinking bag which provides a means of drinking while in the pressure enclosure.

  The ECWS drink bag shall allow convenient crewman drinking while preventing inadvertent activation of the drink valve. The bag shall be capable of being microbiologically cleaned and shall hold a minimum of 24 fluid ounces. The materials used shall not impart any off-taste flavor to the drink.

- Waste Management

  The ECWS shall receive and provide internal storage for 950 cc of urine while pressurized. The Urine Collection Device shall provide for the hygenic collection, storage and disposal of urine and shall be compatible with microbiological cleaning procedures. The UCD shall consist of a container worn inside the ECWS and a replaceable adapter employed as the crewmember interface.

- Overboard Discharge

  It shall be permissible to discharge overboard carbon dioxide, water vapor, and trace comtanimants during normal operation. However, minimizing of water vapor discharge shall be a goal to reduce vehicle water resupply requirements, and to minimize condensation on cooled sensor surfaces. Surface particle generation shall be minimized to reduce deposition on optical surfaces.

- Resupply Interface

  Interface shall be with the projected Space Construction Base. Resupply periods will be 90 days.

- Spatial Orientation

  There shall be no EVA orientation restrictions imposed by the ECWS System.

- Operating Ambient

  All ECWS subsystems shall be designed for oxygen at 4.0 psia and have the capability of operation in an oxygen/nitrogen mixture at 8 psia and 14.7 psia without damage. The ECWS shall be compatible with purging with a mixture of oxygen and nitrogen in an atmosphere of from 9 psia to 14.7 psia.

Performance (Continued)

- Pressure Enclosure Mobility Requirements

The Pressure Enclosure shall provide the following range of motions as a minimum. The maximum torque values accompanying the motion shall be as specified. The torque values denoted by * shall be reduced as feasible to minimize crewman fatigue.

Joint Motion	Min. Mobility Range Degrees	Max. Torque ft-lb
Shoulder-Lateral	150	1.0
Shoulder-Medial	20	1.0
Shoulder-Extension	180	1.8*
Shoulder-Flexion	180	1.8*
Shoulder Rotation (x-z plane)	90	0.5
Shoulder Abduction	150	1.0
Shoulder Abduction	150	1.0
Shoulder Rotation (y-z plane)	120	2.5*
Elbow Flexion/Extension	130	1.0
Forearm Supination	120	2.5*
Forearm Pronation	120	2.5*
Wrist Extension	90	0.5*
Wrist Flexion	90	0.5*
Wrist Adduction	30	0.5*
Wrist Abduction	20	0.5*
Wrist Rotation	180	0.8*
Hip/Waist Flexion	75	4.0
Waist/Spine Rotation	150	9.2
Hip Flexion	70	2.0
Hip Abduction	10	2.0
Knee Mobility (Standing Flexion)	120	1.0
Knee Mobility (Forced Flexion)	150	1.0
Ankle Flexion	40	1.0
Ankle Extension	40	1.0

Performance (Continued)

- Gloves

Gloves shall be provided that are disconnectable at the wrist.

Glove mobility and tactility shall be (TBD) but shall permit such fine motions as turning a 1.0 in. dia. cylinder between the thumb fingers.

Glove insulation on the palm and finger area shall permit grasping hot or cold objects as follows:

Application Pressure Psi	Duration Minutes	Temperature Range °F
2.0	2.0	-180°F to 450°F

- Visibility

Visibility within the helmet shall be as defined below with the head fixed in its primary position, visibility shall be as follows:

Upward (Superior)	90°
Upward, to the Side (Superior temporal)	62°
To the Side (Temporal)	85°
Downward, to the Side (Inferior temporal)	85°
Downward (Inferior)	70°

With head mobility, the visual field shall be at least as follows; and shall be widened beyond these limits as feasible:

Upward	90°
To the Side	120°
Downward	115°

The helmet shall provide sunlight protection to the eyes to avoid discomfort and damage over the range of light intensity from full sunlight to full shade.

Performance (Continued)

- Comfort

The following factors shall be considered relative to crewman comfort during repetitive, long EVA use.

- Proper Sizing - Enclosure and human joint centers shall coincide.

  - The EVA Enclosure shall be free of pressure points and chafe areas.

  - Enclosure design shall consider sizing to fit 5th to 95 percentile male and female crew members and individual crewmembers in the 1985 time frame.

- Non-nutrient - Enclosure materials shall not support microbial growth.

- Odor free - The EVA enclosurematerials shall not adsorb odors and shall be intrinsically odor-free.

- Radiation Protection

The ECWS shall provide radiation protection for the crew during EVA. The level of protection to be provided by the ECWS shall account for the protection provided by the construction base during both the non-EVA portions of EVA days and the non-EVA days that comprise a mission so that the total radiation exposure to the crew during a mission remains within the limits shown below. EVA shall be considered to be unrestricted, that is, shall be capable of being performed at anytime during a scheduled EVA day and shall not be restricted to the low radiation times of the EVA day.

Performance (Continued)

Orbit	EVA During Solar Flares	Dose Limit(1) REM/Quarter
28 1/2° inclination 400 to 500 Km Alt	Yes	63 Skin
55° inclination 400 to 500 Km Alt	No	63 Skin
0° inclination 36.0K Km Alt	No	21 Red BFO (2)
Geosynchronous		31 Eyes

Radiation Environment shall be based upon the following model:

28 1/2° and 55° 400 to 500 Km Low Earth Orbits
- Electrons: AE-5 Solar Min (Most severe)
- Protons: NASA SP-3024, Vol. 5 and 6, with Vol. 5 extended to 50 mev

Geosynchronous
- Electrons: AE-7 High (Most severe)

(1)Exposure to two consecutive operators is permissible provided that no further exposure causes exceedance of yearly limits, namely 225 REM for skin, 112 REM for eyes and 75 REM for red BFO.

(2)Red BFO = Red Blood Forming Organs.

TABLE 1

REQUIREMENTS

The requirements associated with this study are:

Metabolic Rates	Tot 8000 BTU (8 hr.) Avg 1000 BTU/hr.
Profile is per Figure 1	Max 2000 BTU/hr. (15 min.) 1650 BTU/hr. (40 min.) Min 400 BTU/hr. RQ = 0.9
Heat Leak	+ 330 BTU/hr. to -400 BTU/hr.
Oxygen Use Rates	Max .325 lbs/hr. Avg 0.1698 lbs/hr. Metabolic
.065 lbs/hr.	
CO_2 Production	Max .402 lbs/hr. Avg. 0.209 lbs/hr. Min. .080 lbs/hr.
Mission Length	0 to 8 hrs.
Gas Flow Rate to EVA Enclosure	6 cfm minimum
Coolant Flow Rate to EVA Enclosure	240 lbs. H_2O/hr.
CO_2 Partial Pressure	7.6 mmHg maximum 15.0 mmHg maximum @ rates above 1000 BTU/hr. during emergency operation
Suit Pressure Level	4.1 ± .1 psia
Emergency Time	30 minutes
Expendables Replenishment	20 minutes maximum
EVA Enclosure	
Post-sortie interior wipedown, freshening and drying	10 minutes maximum
Donning and Checkout Time	30 minutes maximum

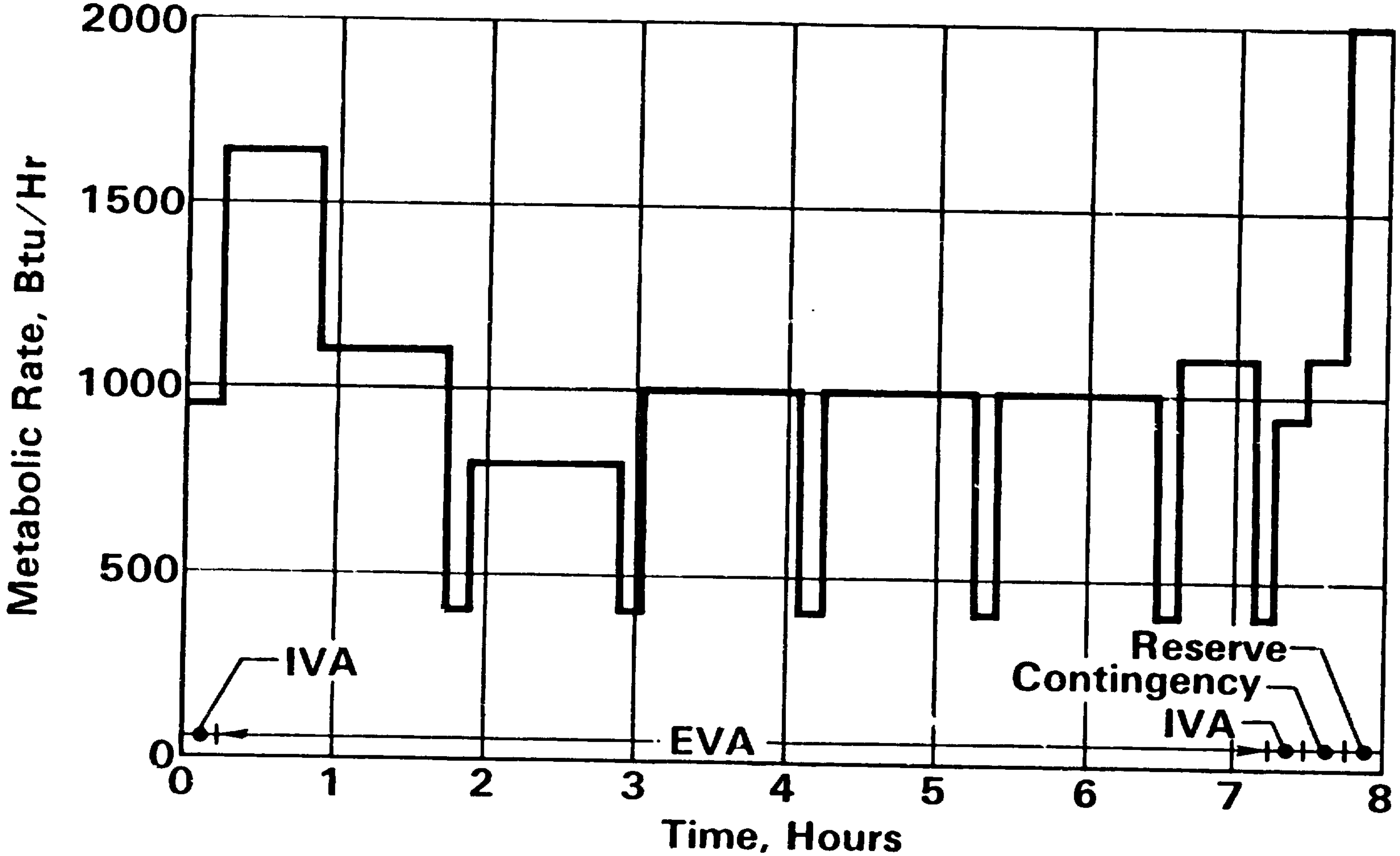
TABLE 2

PENALTIES

The trade penalties associated with this Study are:

	With the EVA Crewman	In the Construction Base
Weight		No equivalent Weight or Volume penalty.
Power	42 watt hrs/lb	
Heat Rejection	1000 BTU/lb	
Volume		Power and heat rejection to be calculated for each ECWS concept and traded on a direct basis
Power	3770 watt hrs/ft^3	
Heat Rejection	62 400 BTU/ft^3	

ECWS METABOLIC PROFILE SPECIFICATION



EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 2, Construction

Introduction

Structure Characteristics

Construction Tasks

Requirements

Concept Evaluation

System Preliminary Design

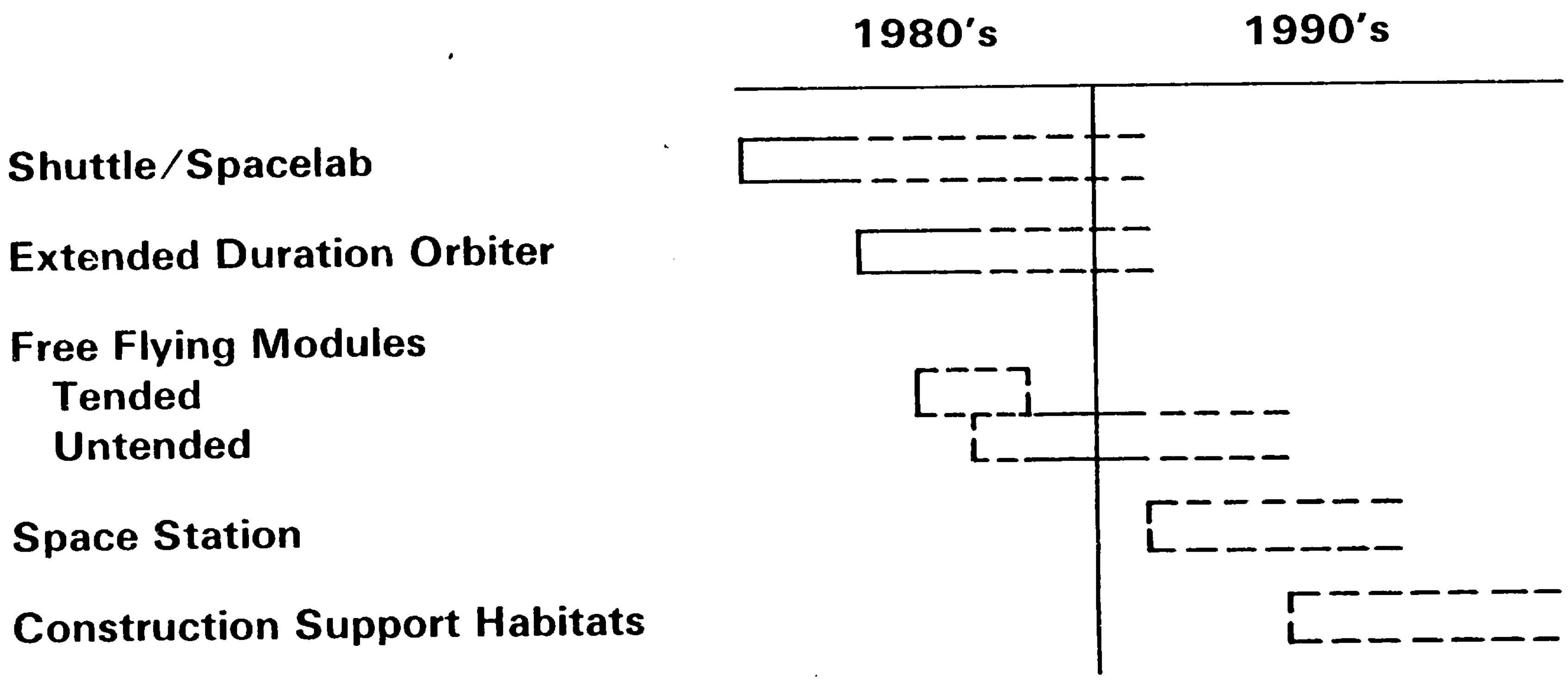
HAMILTON STANDARD
Division of UNITED TECHNOLOGIES

CONCEPT EVALUATION

Evaluation of construction ECWS concepts requires consideration of the evoluation of the manned space program as a whole, because vehicle characteristics essential to ECWS compatibility are expected to change. Hence, a sensitivity analysis was performed to highlight the shifts in the program. This in turn leads to tailoring the ECWS evaluation criteria weighting to each major phase in the manned program.

This section of the report is structured as follows:

MANNED VEHICLES EVOLUTION



MANNED MISSION AND VEHICLE TRENDS

The accompanying table summarizes the characteristics of the projected space program, as it relates to space construction. The accompanying illustration highlights the major changes in program characteristics that affect the ECWS concept evaluation directly.

MANNED MISSION AND VEHICLE TRENDS

Evolutionary Phase / Characteristics	7 Day Shuttle	Extended Duration Orbiter	Free Flying Module	Space Station	Large Structure Construction
Time Frame	1980's, 90's & Beyond	Middle 1980's	Late 1980's	Early 1990's & Beyond	Middle 1990's & Beyond
Mission			Tended / Permanently Manned		
• Duration	0 to 7 Days	7 to 60 Days	30-60 Days / 40-180 Days	–	–
• Crew Size	4-7 People	4-7 People	4-7 People / 3-10 People	5-30 People	100 People Habitat, 3 Habitats/SPS
• Orbit	28½° LEO 55° LEO 98° LEO –	28½° LEO 55° LEO 98° LEO TBD –	28½° LEO 55° LEO 98° LEO TBD GEO TBD	28½° LEO 55° LEO 98° LEO TBD GEO TBD	28½° LEO – – GEO
• Activity	Scientific Research Mfg Process Demo 25 kW Power System Payload Development, Servicing & Retrieval Resupply All Permanently Manned Missions	Scientific Research Mfg Process (Small Scale) 25 kW Power System Perform Structure Feasibility Testing	Scientific Research Mfg Process (Commercial Scale) Build & Test Initial SPS/PSP Demo & Test Articles, & Const Facility	Scientific Research Mfg Process/Commercial Scale Build & Test Service Advanced SPS/PSP Demo & Test Articles	Build, Checkout, Activate, & Service Full Scale SPS/PSP's
• EVA					
No. EVA Crew	2 People	TBD	2-4 People	TBD	~300 People/SPS
Sortie Frequency	4 Nom, 6 Max/Crewman/Flight	Up to 6 Days/Week	6 Days/Week	6 Days/Week	6 Days/Week
Sortie Duration	Up to 7 Hours	6-8 Hours	6-8 Hours	6-8 Hours	4-8 Hours
• Prebreathe	Required	Not Req'd	Not Req'd	Not Req'd	Not Req'd
ECWS Design Drivers					
• Radiation	28½° LEO, 55° LEO, 98° LEO – No Problem – Duration Too Short	28½° LEO – No Problem 55°, 98° – Potential Problem for Repeated EVA's	28½° LEO – No Problem 55° – Problem for Habitat & ECWS 98° – Potential Problem for Habitat/ECWS GEO – Problem for Habitat & ECWS	28½° LEO – No Problem 55° – Problem for Habitat & ECWS 98° – Potential Problem for Habitat/ECWS GEO – Problem for Habitat & ECWS	28½° LEO – No Problem – – GEO – Problem for Habitat & ECWS
• Consummables Management			Tended / Permanently Manned		
Power	Fuel Cells	Solar, Augmented by Fuel Cell	Solar / Solar	Solar	Solar
H_2O	Fuel Cells	Stored, Augmented by Fuel Cell	Stored, Recycled / Stored, Recycled Saved	Stored, Recycled, Saved	Stored, Recycled, Saved
O_2	900 psia Cryo	900 psia Cryo	900 psi Cryo / WVE or TBD	Electrolysis	Electrolysis
CO_2 Removal CO_2 Reduction	LiOH Expendable Dump	HSC Regenerable Dump	HSC Regenerable Dump / HFM or HDC – Dump	HDC – Sabatier to Produce H_2O	HDC – Sabatier to Produce H_2O
• EVA Tasks	Payload Deployment/Retrieval Payload Maintenance/Servicing Small Structure Deployment	Payload Deployment/Retrieval Payload Maintenance/Servicing Fabrication & Assembly Demo.	Test Article Construction, Oper. and Servicing and Maintenance	Test Article Construction, Oper. Servicing and Maintenance	Full Scale Structure Construction Operation, Servicing, and Maintenance
• EVA Transit Distance	100' w/Communications Umbilical 100m w/MMU	150' 100m w/MMU	1000' 100m w/MMU	300m	Up to 13 km for SPS

MANNED MISSION AND VEHICLE TRENDS AFFECT ECWS CONCEPT SELECTION

	Early '80's Shuttle-Spacelab	Middle '80's EDO	Late '80's Free-Flying Modules	Early '90's Space Station	Middle '90's Habitats
Technology Availability	Present Technology →		New Technology →		
Weight	Shuttle-Launched Payloads →				HLLV-Launched Payloads
Power	Cryo O_2/H_2 Fuel Cell →				
		25 kW →		TBD kW →	
Vehicle Volume for EVA Support	Shuttle A/L →		Derived from Shuttle A/L		Designed for Projected EVA →
	Low →		Increasing →		High →
Cost	DDT&E Funded →	New DDT&E Funding Tight New Concepts Must Be Effective to Compete →			EVA Funding Reqts Small Relative to Full Scale Construction Costs

DDT&E = Design, Development, Test & Evaluation

SENSITIVITY ANALYSIS METHOD

The manned space program is a moving target, both in terms of the projected steps thus far identified and in the uncertainties in following those steps. Hence, the ECWS concepts must retain general applicability, and not become tied to any one program concept. However, certain macroscopic trends in the manned space program are inescapable, and it is to these that the ECWS concepts must be carefully attuned.

The method chosen for ECWS to track the trends is to perform a "sensitivity analysis". This identifies the best subsystem choices for each program step, and thus identifies the points at which the ECWS concept must change, and also identifies those concepts which are relatively insensitive to program change and can thus remain constant.

The sensitivity analysis is applied in two ways:

- Qualitatively
- Quantitatively

For those ECWS concepts evaluated qualitatively, the program trends identify the program time frame for which particular concept attributes become applicable or obsolete. This drives considerations of technology availability, new technology planning, and potential useful life for ECWS concepts in question.

For those ECWS concepts evaluated quantitatively, the program trends are used to "fine tune" the relative weighing of the concept selection criteria, according to the following sensitivity analysis considerations:

- ECWS is a long term concept. Technology availability constrains concept selection for the middle 1980's, which includes the ECWS IOC. However, for the later 1980's and beyond, time exists to develop new technologies, which opens up the range of ECWS concept options for consideration.

- For Shuttle-supported construction missions ECWS resupply requirements will compete with structure payload for the 15 ft by 60 ft cylindrical volume and 65,000 lb weight capability of the Shuttle. Large scale construction, on the other hand, is expected to use an HLLV concept to launch structure payloads. ECWS resupply considerations will be a much smaller fraction of such payloads and, therefore, ECWS equivalent weight and volume significance will become somewhat reduced.

SENSITIVITY ANALYSIS METHOD (Continued)

- The present Shuttle devotes just a 150 ft^3 airlock and a small mid-deck area with some stowage lockers to EVA provisions. This limits ECWS EVA volume to essentially that of the EMU out through the EDO phase. Modules, as concepted in the SSSAS reports, are shown to have an expanded adjacent volume, which could be used to store and service EVA equipment that is somewhat larger than the EMU, as long as the system can pass through the 1 m dia international docking hatch. Further in the future, construction habitats would be configured to support EVA as their primary purpose, and thus their volume allotments would be driven by ECWS considerations. Structure too, will become more spacious, minimizing the requirements for access to small or narrow spaces. Thus, the long term trend is for EVA volume to decline somewhat in significance.

- Until a national commitment to large scale space construction is made, EVA DDT&E money will be tight. Concept candidates will be carefully screened for cost effectiveness. However, once a large scale construction program commitment has been made it is expected that EVA costs will become a smaller fraction of the total program. Thus, EVA costs will be expected to decline somewhat in significance.

- EVA will increase as the scope of construction projects increase. Accordingly, the orientation of the space worker will change from that of the scientist/engineer, who develops construction capability in space, to that of the construction worker who uses the capability to perform useful work inspace. Thus the ECWS will become more like a tool, in which utility and dependability become increasingly important. Therefore, operability, maintainability, reliability and EVA weight will increase in significance as the scope of construction activity increases.

ECWS EVALUATION CRITERIA

ECWS evaluation criteria are presented in the accompanying table which shows the criteria that are applicable to the EVA enclosure, life support packaging and life support subsystems. The table shows that some criteria that are useful for highlighting significant difference between subsystem concepts are not useful in differentiating between packaging concepts or enclosure concepts.

EVA enclosure concept selection is not sensitive to vehicle weight, as there are no high-use expendables requiring resupply. Enclosure selection is not sensitive to EVA weight and volume because differences between concepts have small impacts.

Life support packaging concepts are not sensitive to performance, availability, crew acceptability, equivalent vehicle weight and volume, and cost and interface compatibility (with vehicle), because these are determined by choice of life support subsystem concept.

ECWS EVALUATION CRITERIA

	LSS Subsystems	LSS Packaging	EVA Enclosure
Safety	X	X	X
Cost	X		X
Interface Compatability	X		X
Performance	X		X
Availability	X	Not Affected	X
Crew Acceptability	X		X
Equiv. Vehicle Volume	X		X
Equiv. Vehicle Weight	X		
EVA Volume	X	X	Not Affected
EVA Weight	X	X	
Reliability	X	X	X
Flexibility	X	X	X
Maintainability	X	X	X
Operability	X	X	X

LIFE SUPPORT SUBSYSTEM EVALUATION CRITERIA

To evaluate EVA life support subsystem concepts, evaluation criteria were developed to assure objective consideration of the EVA subsystem candidates.

The determination of the evaluation criteria is based on a recognition that some requirements are absolute, others are of primary importance, and still others are secondary in that they are desirable but not absolutely necessary. The criteria are supplied sequentially in the groups shown to eliminate concepts that fail in either an absolute (go/no-go) or comparative basis and to provide the basis to evaluate surviving candidates.

Go/no-go criteria define the minimum acceptable requirements for a concept. If a concept does not meet or cannot be modified to meet all of the go/no-go criteria, no further consideration is given to that concept, and it is eliminated. The go/no-go criteria are listed as follows:

Performance - All concepts must be capable of meeting the entire performance specification to be considered as candidates. To provide a common basis, concepts are adjusted for each competing subsystem to meet the same performance requirements.

Safety - Safety of each concept is evaluated with respect to fire, contamination, explosion hazards, hot spots, bacteriological problems, and crew hazards to determine if any of these are present which cannot be eliminated by careful design or inclusion of additional control equipment, different materials, etc. Hazards are investigated during normal operation and off-design operation. If any serious problems are discovered which cannot be reasonably avoided, the concept is eliminated.

Availability - Availability is a measure of the probability of a concept having fully developed technology within the middle 1980's time period. Preliminary screening of concepts eliminates many questionable concepts where feasibility has not been convincingly established. Availability is evaluated by an analysis of the subsystem approach, its interfaces and hardware requirements to define problem areas, and design "qualms". Concepts demand otherwise promising are identified as requiring state-of-the-art development and estimates are made of schedule requirements for new technology advancement to assess potential applicability for the time period of the late 1980's.

LIFE SUPPORT SUBSYSTEM EVALUATION CRITERIA (Continued)

Crew Acceptability - This is a measure of the psychological acceptability of the subsystem by the eventual user. The subsystem must be designed to assure that it imposes a minimal operational stress on the crew. If a concept is deemed to be unacceptable to the crew and cannot be corrected, that concept is eliminated.

All candidate concepts that pass the go/no-go evaluation are subjected to the primary evaluation. Each candidate concept receives a rating for each primary criterion. The ratings applied to a candidate concept are dependent upon the characteristics of the candidate relative to the other candidates.

The primary criteria are defined as follows:

Vehicle Equivalent Weight - The physical aspects of any given concept can be converted to an equivalent vehicle launch weight penalty for purposes of comparison. Equivalent vehicle weight consists of subsystem fixed weight, expendables, recharge and/or regeneration equipment, spares, and special interface equipment.

EVA Volume - EVA equipment volume consists of all EVA life support equipment with which the crewman must egress from the vehicle and is an indirect measurement of crewman encumbrance and mobility hindrance. This criterion provides an objective quantitative basis for evaluation, and, in conjunction with equivalent vehicle weight, represents one of the two most important evaluation criteria for use during the study.

Cost - Front-end non-recurring cost and program recurring costs will be assessed for the concept candidates.

Reliability - Reliability is an estimate of the probability of freedom from malfunction and is based on considering the number of dynamic components in the subsystem concepts.

Flexibility - Flexibility is a measure of the concept's ability to be used under various conditions at minimum penalty:

- Different types of EVA missions such as cargo transfer, assembly operations, or maintenance and checkout, lasting from 4 to 8 hours, and compatible with 4 to 8 psig operation.

LIFE SUPPORT SUBSYSTEM EVALUATION CRITERIA (Continued)

The secondary evaluation represents a step in depth of competitive evaluation. Ratings of the candidate concepts against secondary characteristics are relative assessments within each area of consideration as in the implementation of the primary criteria. Those concepts which score relatively high are considered to have passed the secondary evaluation; those that score low are rejected and eliminated from further consideration.

In all cases, the secondary criteria are applied against all concepts to provide a systematic review of the overall acceptability of these concepts to ensure that secondary characteristics would not preclude their use.

The secondary criteria are defined as follows:

Vehicle Equivalent Volume - Vehicle equivalent volume is a volumetric measure of the subsystem, expendables, recharge and/or regeneration equipment and special interface equipment, and is a "second-order" tool which provides an objective quantitative basis for evaluation.

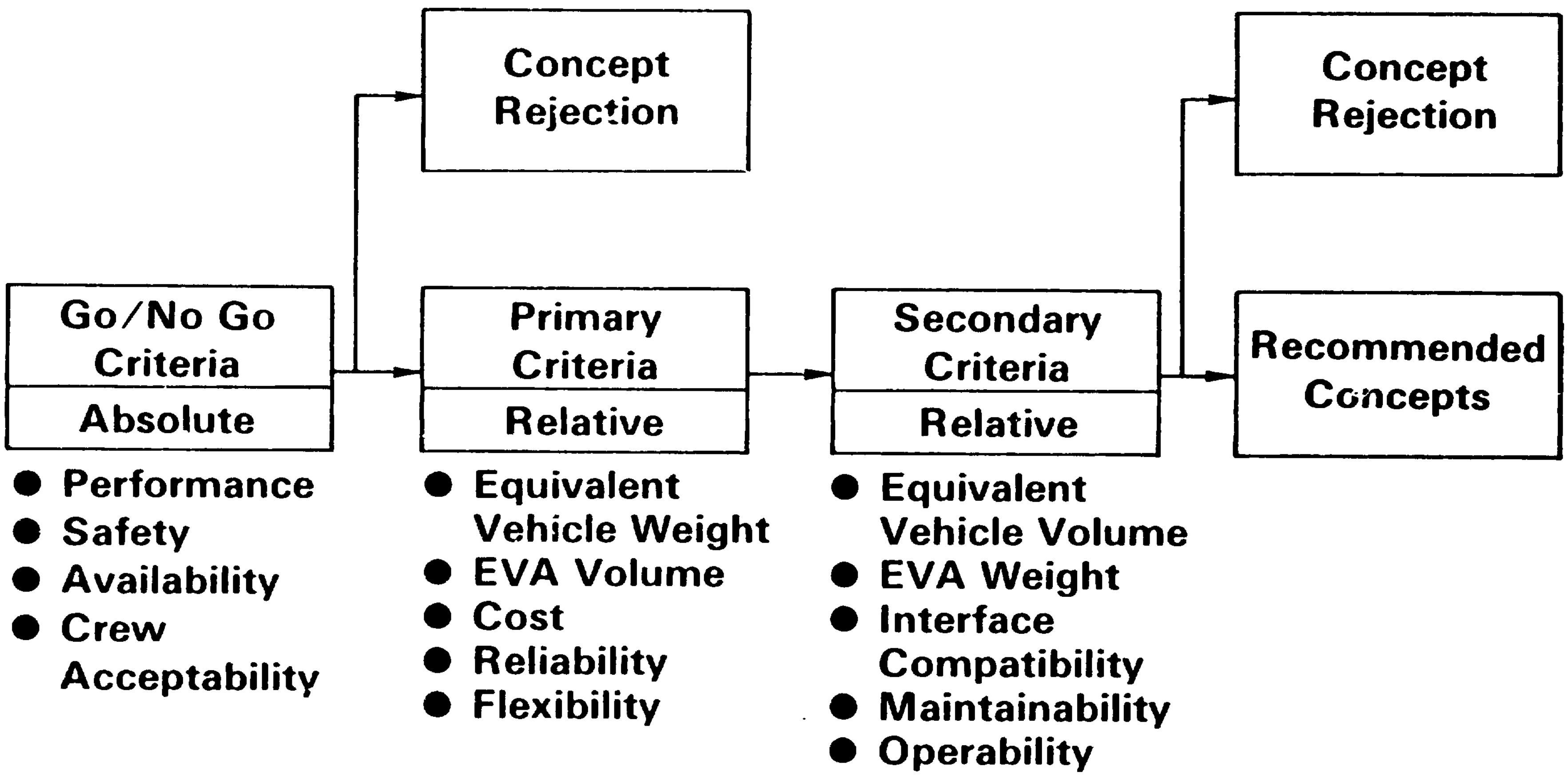
EVA Weight - Since this criterion is directly considered in the primary criteria of vehicle equivalent weight, the primary emphasis of weight in the secondary criteria is the limiting factor of ability to handle, service, move, replace, or install the equipment, and the effect upon the total EVA system center of gravity.

Interface Compatibility - This is a measure of the ability of the concept to integrate with other subsystems or components, the crew, the space suit and the vehicle without a severe penalty on the other areas. Because of the physical and functional scope of the ECWS, an interface check is necessary to assure that no unreasonable problems are encountered in the eventual integration of the ECWS in the total mission/vehicle system.

Maintainability - Maintainability is an assessment of the time required for checkout, replacement of expendables, regeneration of components or subsystems, cleaning, and scheduled and unscheduled maintenance where such operations are required. This assessment is made after a satisfactory design concept is evolved with respect to performance, spares, redundancy, and modularity.

Operability - Operability is a measure of the concept's simplicity of use during the mission's various operating modes including: don/doff, startup, checkout, egress/ingress, shutdown, recharge/regeneration, and operational variations during the actual EVA.

LIFE SUPPORT SUBSYSTEM EVALUATION CRITERIA



SYSTEM PACKAGING CONFIGURATION CONCEPT EVALUATION CRITERIA

To evaluate system packaging concepts, evaluation criteria were developed to assure objective consideration of the system packaging configurations.

The determination of the EVA system packaging configurations evaluation criteria is based on a recognition that some requirements are absolute, others are of primary importance, and still others are secondary in that they are desirable but not absolutely necessary. The criteria are applied sequentially in the groups shown to eliminate concepts that fail in either an absolute (no/no-go) or comparative basis and to provide the basis for selection between surviving candidates.

Go/no-go criteria define the minimum acceptable requirements for a concept. If a concept does not meet or cannot be modified to meet the go/no-go criteria, no further consideration is given to that concept and it is eliminated. The go/no-go criteria are listed as follows:

Safety - Safety of each concept is evaluated with respect to requiring no low pressure umbilical disconnection in a vacuum, and umbilical management not hindering emergency return to the airlock.

All candidate concepts that pass the go/no-go evaluation are subjected to the primary evaluation. Each candidate concept receives a rating for each primary criterion. The ratings applied to a candidate concept are dependent upon the characteristics of the candidate relative to the other candidates.

The primary criteria are defined as follows:

EVA Volume - EVA equipment volume consists of all EVA life support equipment with which the crewman must egress from the vehicle and is an indirect measurement of crewman encumbrance and mobility hindrance. This criterion provides an objective quantitative basis for evaluation, and represents one of the most important evaluation criteria for use during the study.

Flexibility - Flexibility is a measure of the concept's ability to be used easily in various locations and not to waste consummables over EVA sortie durations lasting from 4 to 8 hours.

SYSTEM PACKAGING CONFIGURATION CONCEPT EVALUATION CRITERIA (Continued)

Reliability - Reliability is an assessment of the candidate's ability to perform without malfunction for the specified duration under specified environmental and usage conditions.

The secondary evaluation represents a step in depth of competitive evaluation. Ratings of the candidate concepts against secondary characteristics are relative assessments within each area of consideration as in the implementation of the primary criteria.

In all cases, the secondary criteria are applied against all concepts to provide a systematic review of the overall acceptability of these concepts to ensure that secondary characteristics would not preclude their use.

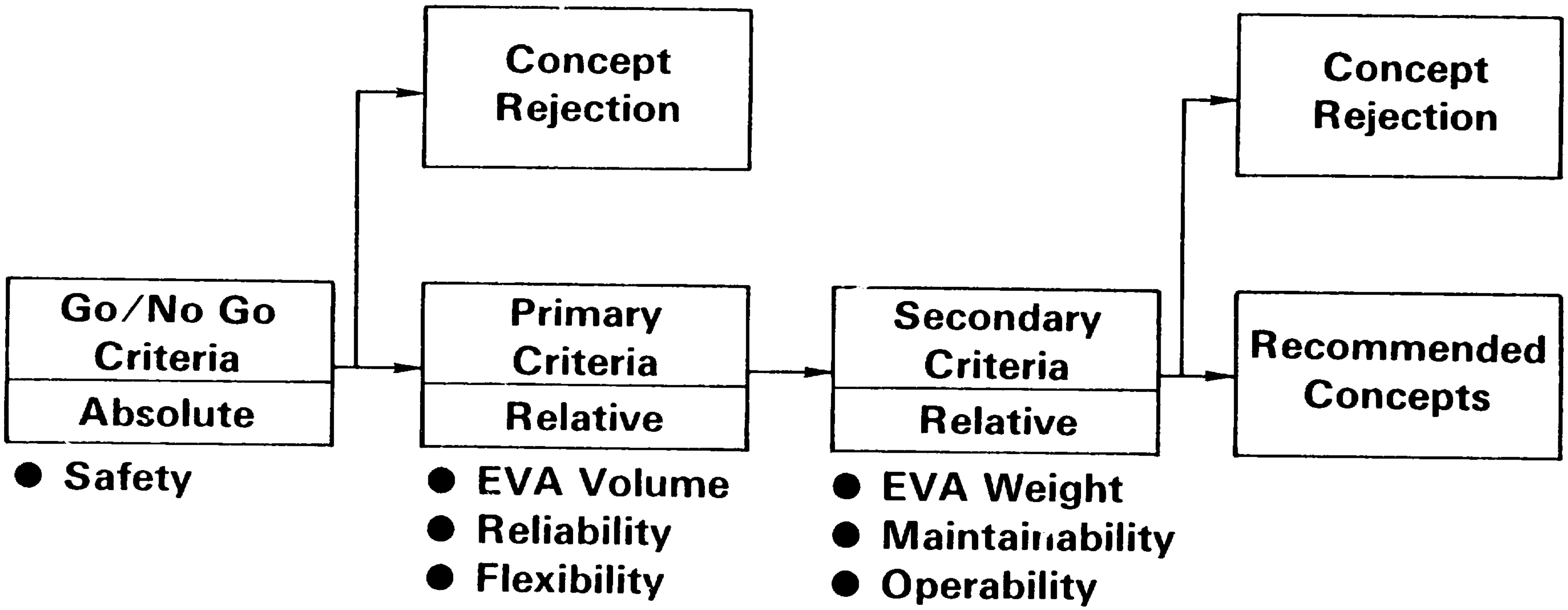
The secondary criteria are defined as follows:

EVA Weight - Since this criterion is directly considered in the primary criteria of vehicle weight, the emphasis of weight in the secondary criteria is the limiting factor of ability to handle, service, move, replace, or install the equipment, and the effect upon the total EVA system center of gravity.

Maintainability - Maintainability is an evaluation of the accessibility for repair and the ease of expendables replacement.

Operability - Operability is a measure of the freedom from attention during transit and the ease of making EVA LSS adjustments during EVA.

LIFE SUPPORT SYSTEM PACKAGING EVALUATION CRITERIA



EVA ENCLOSURE EVALUATION CRITERIA

To evaluate EVA enclosure concepts, evaluation criteria were developed to assure objective consideration of the EVA enclosure elements candidates.

The determination of the evaluation criteria is based on a recognition that some requirements are absolute, others are of primary importance, and still others are secondary in that they are desirable but not absolutely necessary. The criteria are applied sequentially in the groups shown to eliminate concepts that fail in either an absolute (go/no-go) or comparative basis and to provide the basis to evaluate surviving candidates.

Go/no-go criteria define the minimum acceptable requirements for a concept. If a concept does not meet or cannot be modified to meet all of the go/no-go criteria, no further consideration is given to that concept, and it is eliminated. The go/no-go criteria are listed as follows:

Performance - All concepts must be capable of meeting the entire performance specification of life, mobility range, torque, and resistance to mechanical and radiation hazards to be considered as candidates. To provide a common basis, conceptual designs are adjusted for each competing element to meet the same performance requirements.

Safety - Safety of each concept is evaluated with respect to O_2 compatibility. If any serious problems are discovered which cannot be reasonable avoided, the concept is eliminated.

Availability - Availability is a measure of the probability of a concept having fully developed technology within the early 1980's time period. Concepts deemed promising are identified as requiring state-of-the-art development and estimates are made of schedule requirements for new technology advancement to assess potential applicability.

Crew Acceptability - This is a measure of the psychological acceptability of the enclosure by the eventual user in terms of comfort, fit and hygiene. The enclosure must be designed to assure that it imposes a minimal operational stress on the crew. If a concept is deemed to be unacceptable to the crew and cannot be corrected, that concept is eliminated.

EVA ENCLOSURE EVALUATION CRITERIA (Continued)

All candidate concepts that pass the go/no-go evaluation are subjected to the primary evaluation. Each candidate concept receives a rating for each primary criterion. The ratings applied to a candidate concept are dependent upon the characteristics of the candidate relative to the other candidates.

The primary criteria are defined as follows:

Cost - Front-end non-recurring cost and program recurring costs will be estimated and ranked for the concept candidates.

Reliability - Reliability is an estimate of the probability of freedom from malfunction and is based on an assessment of the delicacy and complexity of the concept.

Flexibility - Flexibility is a measure of the concept's ability to support EVA at 4 to 8 psig.

The secondary evaluation represents a step in depth of competitive evaluation. Ratings of the candidate concepts against secondary characteristics are relative assessments within each area of consideration as in the implementation of the primary criteria.

In all cases, the secondary criteria are applied against all concepts to provide a systematic review of the overall acceptability of these concepts and to ensure that secondary characteristics would not preclude their use.

The secondary criteria are defined as follows:

Vehicle Equivalent Volume - Vehicle equivalent volume is a volumetric measure of the spares requirement, and is a "second-order" tool which provides an objective quantitative basis for evaluation.

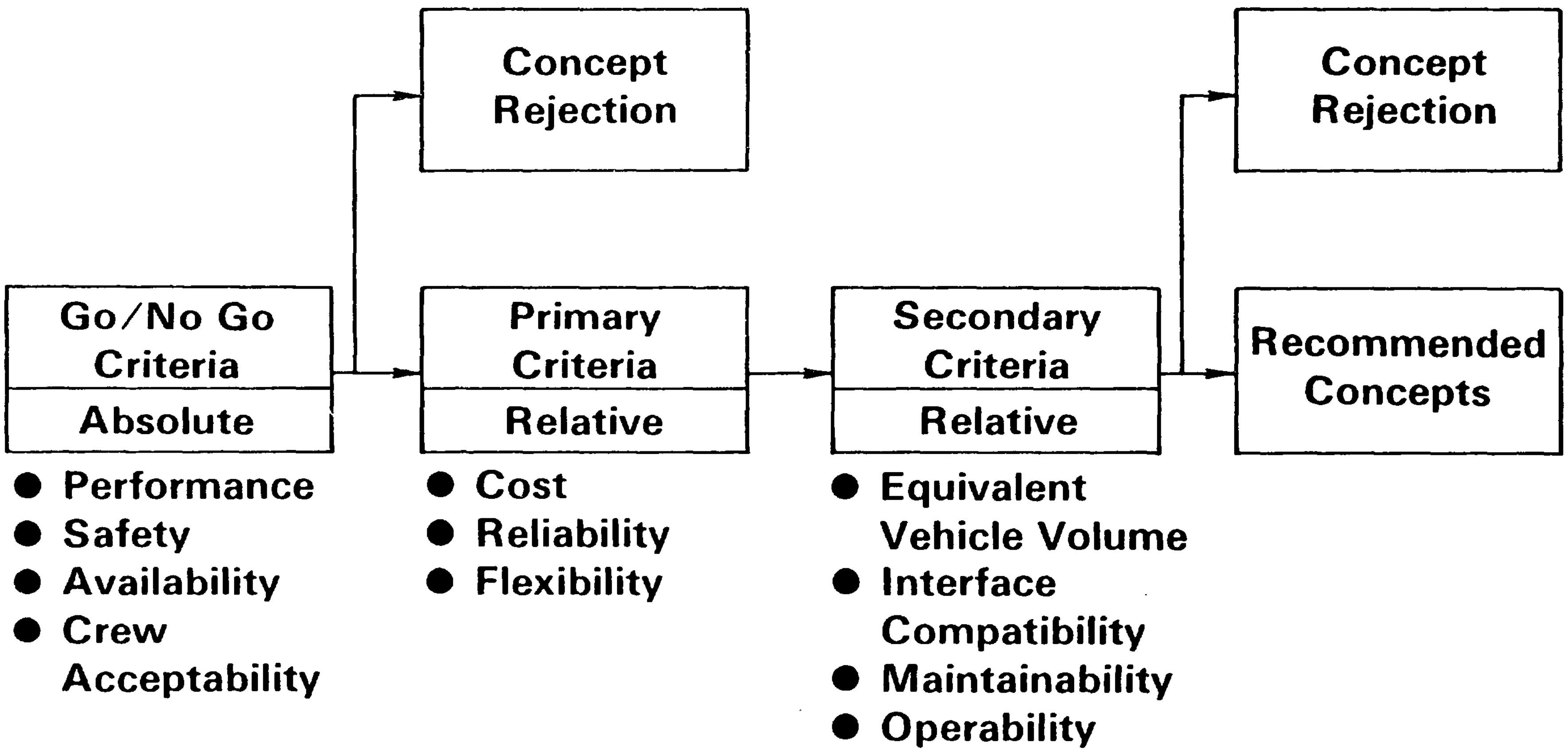
EVA ENCLOSURE EVALUATION CRITERIA (Continued)

Interface Compatibility - This is a measure of the ability of the concept to integrate with other ECWS subsystems, the crew and the vehicle without a severe penalty on the other areas. Because of the physical and functional scope of the ECWS, an interface check is necessary to assure that no unreasonable problems are encountered in eventual integration of the ECWS in the total mission/vehicle system.

Maintainability - Maintainability is an assessment of the time required for checkout, cleaning, and scheduled and unscheduled maintenance where such operations are required.

Operability - Operability is a measure of the concept's simplicity of use during the mission's various operating modes including: don/doff, and post-EVA servicing.

EVA ENCLOSURE EVALUATION CRITERIA



EXISTING CONCEPTS VS NEW TECHNOLOGY

ECWS draws on both well developed, existing concepts, and new concepts requiring future technology development.

Existing concepts can be evaluated quantitatively because the feasibility has already been demonstrated and/or a sufficient data base exists to permit preliminary sizing calculations to be made.

New technology concepts do not have such a data base, and therefore must be evaluated qualitatively.

Most of the life support subsystem concepts using existing technology, or at least have had their feasibility demonstrated. Hence, these concepts, and the packaging concepts using these subsystems, were evaluated quantitatively.

The EVA enclosure, however, represents new requirements whose feasibility has not been demonstrated in all cases. Hence, the EVA enclosure concepts were evaluated qualitatively.

System integration concepts involve the EVA enclosure in most cases, and therefore, were also evaluated qualitatively.

EXISTING CONCEPTS & NEW TECHNOLOGY

	Existing Concepts	New Technology
Feasibility	Demonstrated	No Demonstrated
Data Base for Sizing Calculation	Adequate	Inadequate
Concept Evaluation	Quantitative	Qualitative
ECWS Areas	LSS Subsystems and Packaging	EVA Enclosure and System Integration

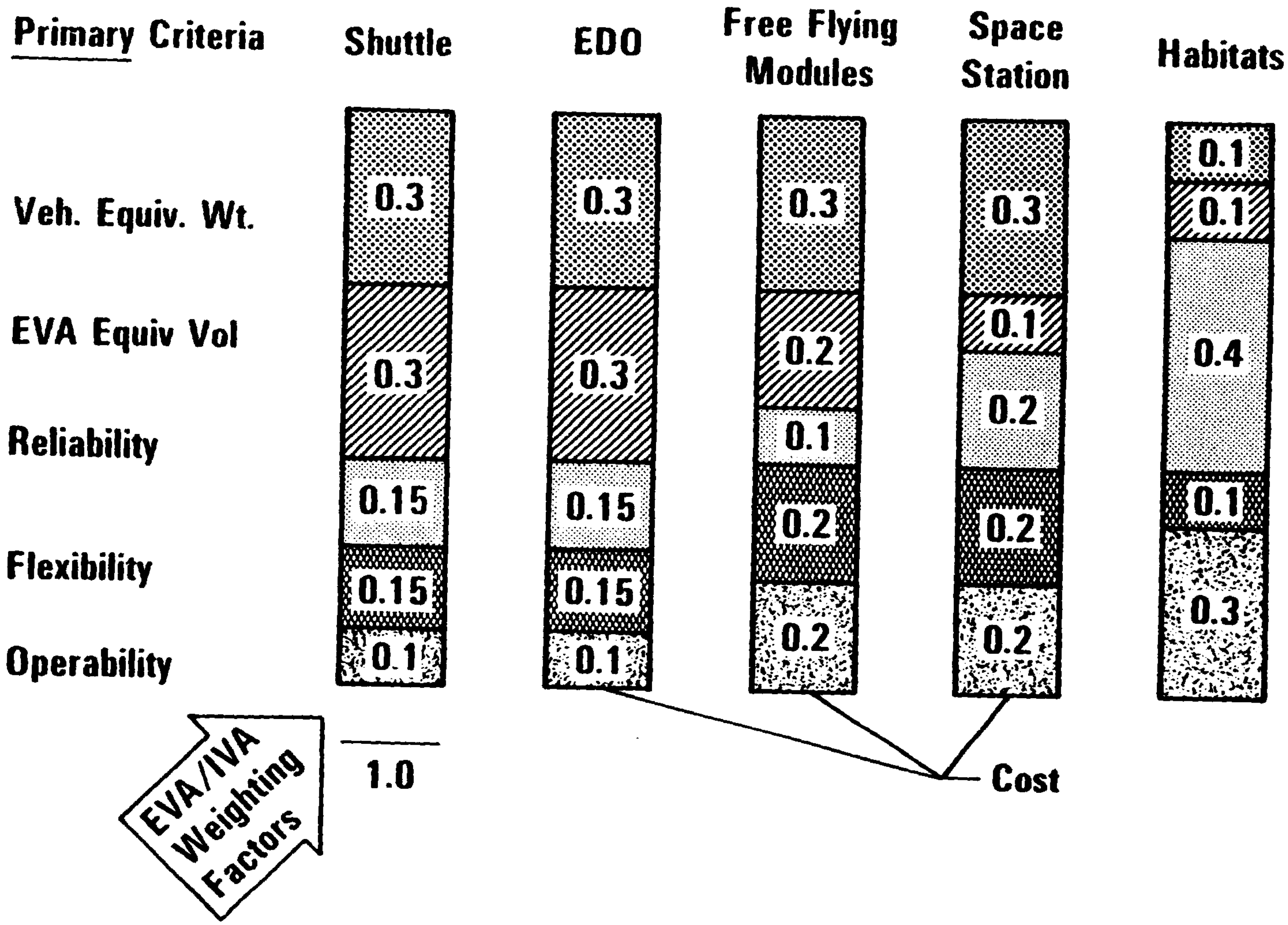
SENSITIVITY ANALYSIS FOR QUANTITATIVE EVALUATION

Changes in relative importance of the life support subsystems and packaging selection criteria drive changes in the weighting factors, which are the multipliers applied to the numerical evaluation of each selection criterion. The accompanying illustrations show how the major trends in the manned space program are reflected in the selection criteria weighting factors at each step in the program. ECWS concepts were evaluated at each program step to determine what program changes force changes in ECWS concept selection, thus yielding an assessment of the concepts sensitivity to program changes.

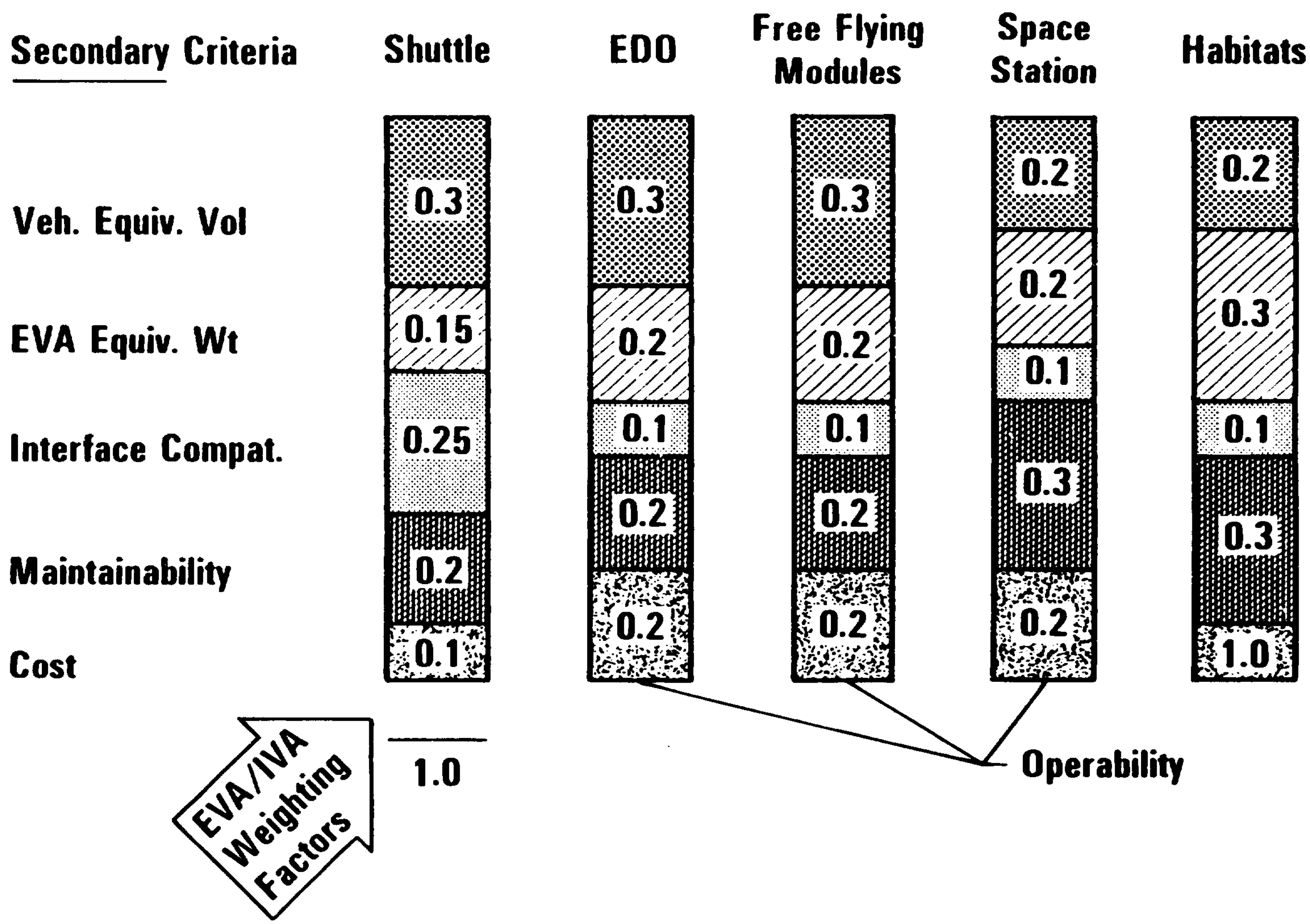
ECWS SELECTION CRITERIA WEIGHTING FACTORS

Selection Criteria	7 Day Shuttle		Extended Duration Orbiter			Free Flying Modules			Space Station			Large Structure Construction		
	Shuttle EVA/IVA & AEPS Studies		First ECWS Use	System	Sub System	ECWS for Test & Demo Article Const	System	Sub System	ECWS for Test & Demo Article Const.	System	Sub System	(ECWS for Full Scale SPS & PSP Const.	System	Sub System
Go/N Go														
• Performance	Ability to Meet Specified Performance	X	(Criteria Are N/A at System Level Because Applicability is Determined at Subsystem Level.)	N/A	X		N/A	X		N/A	X		N/A	X
• Safety	Freedom from Hazards to Crew	X		X	X		X	X		X	X		X	X
• Availability	Concept Maturity to Support Mission Timetable	X		N/A	X		–	–		–	–		–	–
• Crew Acceptability	Freedom from Psychological Stress During Use	X		N/A	X	(Availability of Technology No Longer an Issue – 10 Yr. Lead Time Sufficient to Develop Otherwise Viable Concepts.)	N/A	X		N/A	X		N/A	X
Primary														
• Vehicle Equip. Weight	Impact of EVA Equip. on Shuttle Launch Wt.	0.3		N/A	0.3		N/A	0.3		N/A	0.3	(Launch Wt. Decreases in Importance as HLLV Assumes ECWS Resupply Burden.)	N/A	0.1
• EVA Equip. Volume	Impact of EVA Equip. on Shuttle A/L Vol	0.3	(Uses Shuttle A/L, ECWS is Larger Than EMU.)	0.4	0.3	(Volume Importance Decreases as Modules Retain Shuttle A/L, But Permit Don Doff, Service & Stowage in Areas Outside A/L.)	0.3	0.2	(Volume Decreases in Importance as Station Will Have A/L Configured to ECWS.)	0.2	0.1			
• Reliability	Includes No. of Failure Modes & Life	0.15		0.3	0.15	(Subsystem Level Reliability Decreases in Importance Relative to Flexibility.)	0.3	0.1	(Reliability Gains in Importance at Subsystem Level As Increased ECWS Use Requires Long Life.)	0.4	0.2	(Reliability Gains in Importance At Subsystem Level As Increased ECWS Use Requires Long Life.)	0.4	0.4
• Flexibility	Adaptability to Different Missions & New Technology	0.15		0.3	0.15	(Flexibility Gains Importance As System Level Use Locations Increase. At Subsystem Level Adaptability to New Technology Rises in Significance.)	0.4	0.2	(At System Level Workplace Hazards Increase with Rise in Structure Size.)	0.4	0.2	(Flexibility Decreases in Importance Relative to Reliability, as Tasks Become Standardized.)	0.3	0.1
• Cost		–	(Late 1970's Economic Conditions Dictate Low Front End Costs.)	N/A	0.1	(Nonrecurring Costs for New Technology Rise in Significance. Recurring Costs for Shuttle Resupply Rise in Significance.)	N/A	0.2		N/A	0.2	(Cost of ECWS Declines in Importance Relative to Total Cost of PSP or SPS Program. Cost Becomes a Secondary Criterion.)		
• Operability	Ease of Use in All EVA Mission Phases	0.1	(Cost Becomes More Important Than Operability in This Time Period. Operability Becomes a Secondary Criterion.)	–	–		–	–		–	–	(Operability Becomes a Primary Criterion for the Achievement of EVA Productivity.)	0.1	0.3
		1.0		1.0	1.0		1.0	1.0		1.0	1.0		1.0	1.0
Secondary														
• Vehicle Equip. Volume	Impact of EVA Equip. on Shuttle Expendables & Service Area Vol	0.3		N/A	0.3		N/A	0.3	(Volume Decreases in Importance as Station will Be Configured for ECWS Stowage, Servicing & Maintenance.)	N/A	0.2		N/A	0.2
• EVA Equip. Weight	Impact of EVA Equipment Mass on EVA Crewman	0.15	(At System Level EVA Wt. Maintainability & Operability Become Essentially Equivalent in Determining EVA Productivity.)	0.3	0.2		0.3	0.2		0.3	0.2	(EVA Weight Gains in Importance in Routine ECWS Use to Reduce Fatigue.)	0.6	0.3
• Interface Compatibility	Freedom from Incompatibility with Other Vehicle Systems	0.25		N/A	0.1		N/A	0.1		N/A	0.1		N/A	0.1
• Maintainability	Ease of On Orbit Checkout, Recharge & Service	0.2	(At Subsystem Level EVA Wt. & Operability Become More Important Than Interface Compatibility, as EVA Productivity Overshadows Retention of Shuttle EMU Interfaces.)	0.3	0.2		0.3	0.2	(Subsystem Maintainability Gains in Importance as ECWS Use Increases.)	0.3	0.2	(System Level Maintainability Gains in Importance as ECWS Use Increases.)	0.6	0.3
• Operability	Simplicity of Use During All EVA Mission Phases			0.4	0.2		0.4	0.2		0.4	0.2		–	–
• Cost	Recurring and Non Recurring	0.1		–	–		–	–		–	–		N/A	0.1
	Total	1.0		1.0	1.0		1.0	1.0		1.0	1.0		1.0	1.0

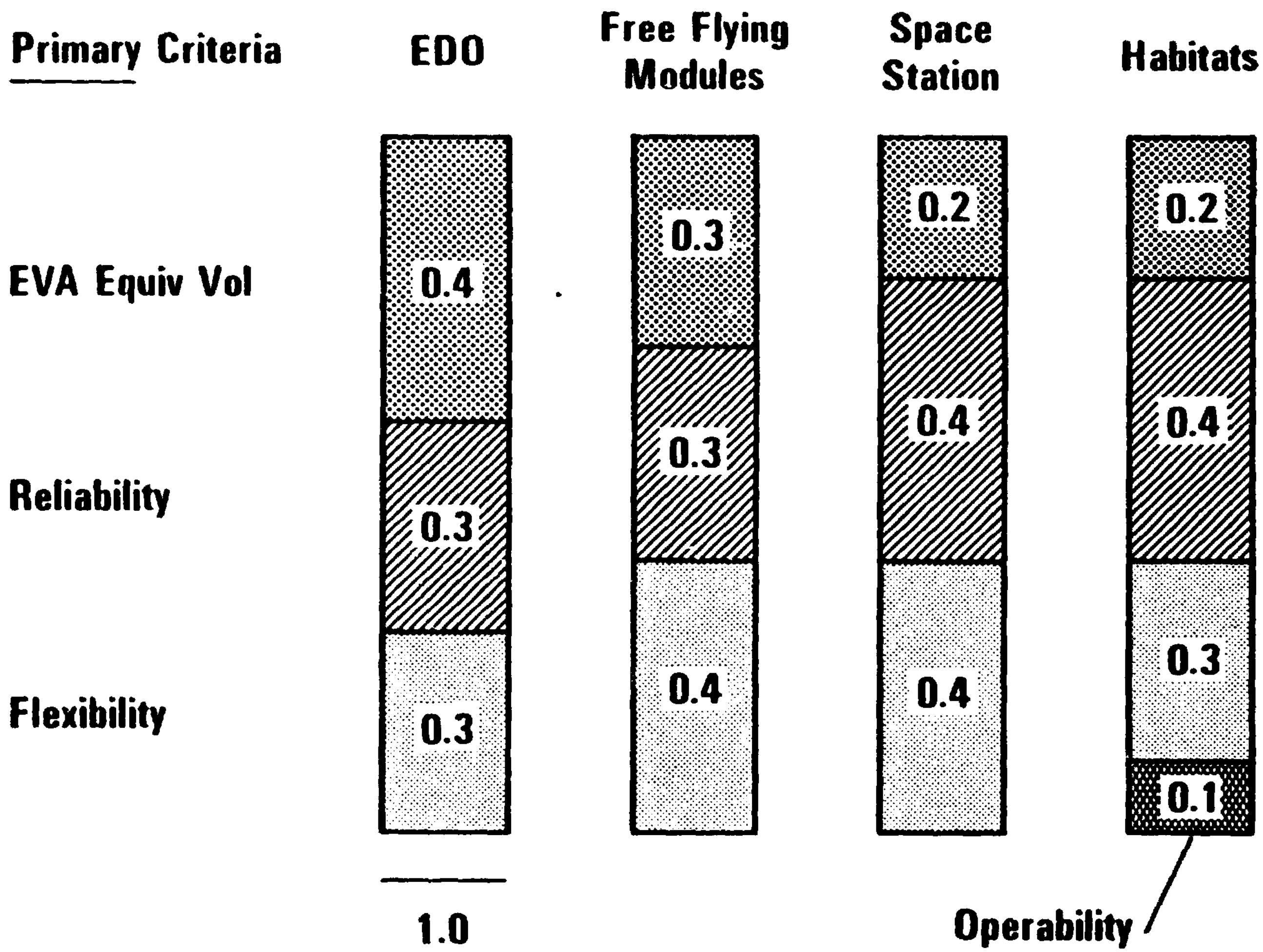
EFFECT OF SPACE PROGRAM CHARACTERISTICS CHANGES ON ECWS LSS SUBSYSTEM SELECTION WEIGHTING FACTORS



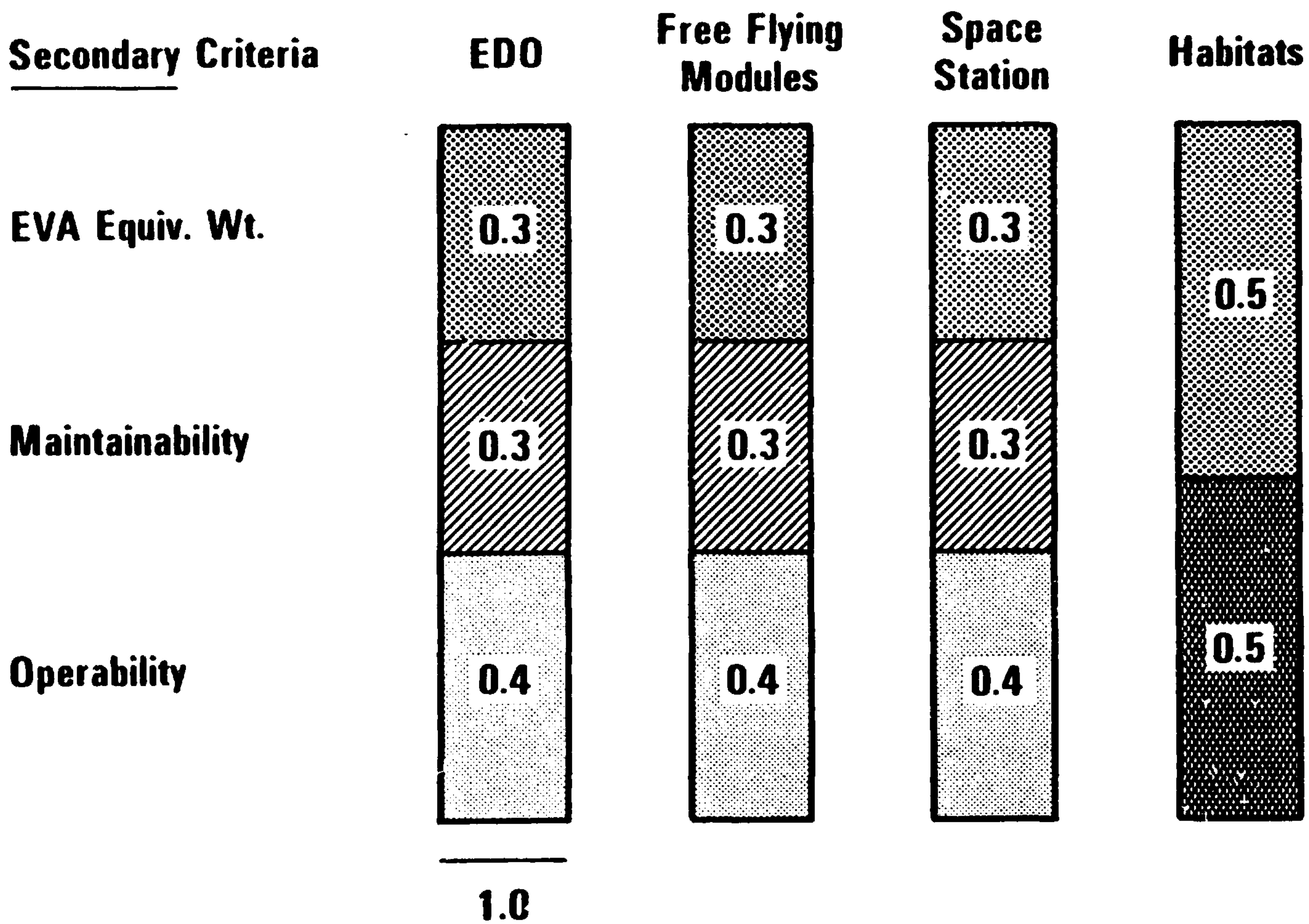
EFFECT OF SPACE PROGRAM CHARACTERISTICS CHANGES ON ECWS LSS SUBSYSTEM SELECTION WEIGHTING FACTORS



EFFECT OF SPACE PROGRAM CHARACTERISTICS CHANGES ON ECWS LSS PACKAGING SELECTION WEIGHTING FACTORS



EFFECT OF SPACE PROGRAM CHARACTERISTICS CHANGES ON ECWS LSS PACKAGING SELECTION WEIGHTING FACTORS



RATING SCALES

Weight and volume parameters are evaluated numerically and then assessed relative to a zero-to-maximum range driven by vehicle and launch requirements outside the range of the LSS subsystem values studies. The maximum end points are as follows:

Pack Volume -	LSS Subsystem =	1/2 hatch area x 1/2 astronaut height
	Volume =	13.9 ft^3/4 subsystems = 3.5 ft^3
Vehicle Weight -	10% of resupply weight is for any one LSS subsystem = 6500 lbs	
Pack Weight -	Maximum weight for any one ECWS subsystem is 150 lbs	
Vehicle Volume -	Maximum LSS Expendables Storage Volume = 400 ft^3 per subsystem	

The cost rating is determined by dividing cost into two sub-areas and weighting each as follows:

Recurring Cost	3 points
Non-Recurring Cost	7 points
	10 points

A relative quantitative assessment of each candidate concept is made and the sum of the ratings of the two sub-areas is equal to the total cost rating for each candidate concept. The assessment is based on a 0 to 10 scale where a rating of 0 represents $3,000,000 for non-recurring and $1,000,000 for recurring costs, as shown in the accompanying figure.

The reliability rating is a quantitative comparative assessment of candidate concepts and is based upon the total number of subsystem component failures that could cause mission abort and/or loss of life. The assessment is based on a 0 to 10 scale, where a rating of 0 represents 10 potential component failures as shown in the accompanying figure.

The flexibility rating is determined qualitatively by dividing flexibility into two sub-areas and weighting each area as follows:

RATING SCALES (Continued)

Ability to support 400 to 2000 Btu/Hr metabolic load	5 points
Ability to support 4 to 8 hr. mission without waste	5 points
	10 points

The interfacing compatibility rating is determined qualitatively by dividing interface compatibility into three subareas and weighting them as follows:

Other LSS Subsystem Interfaces	2 points
Crew Interfaces	5 points
Vehicle Interfaces	3 points
	10 points

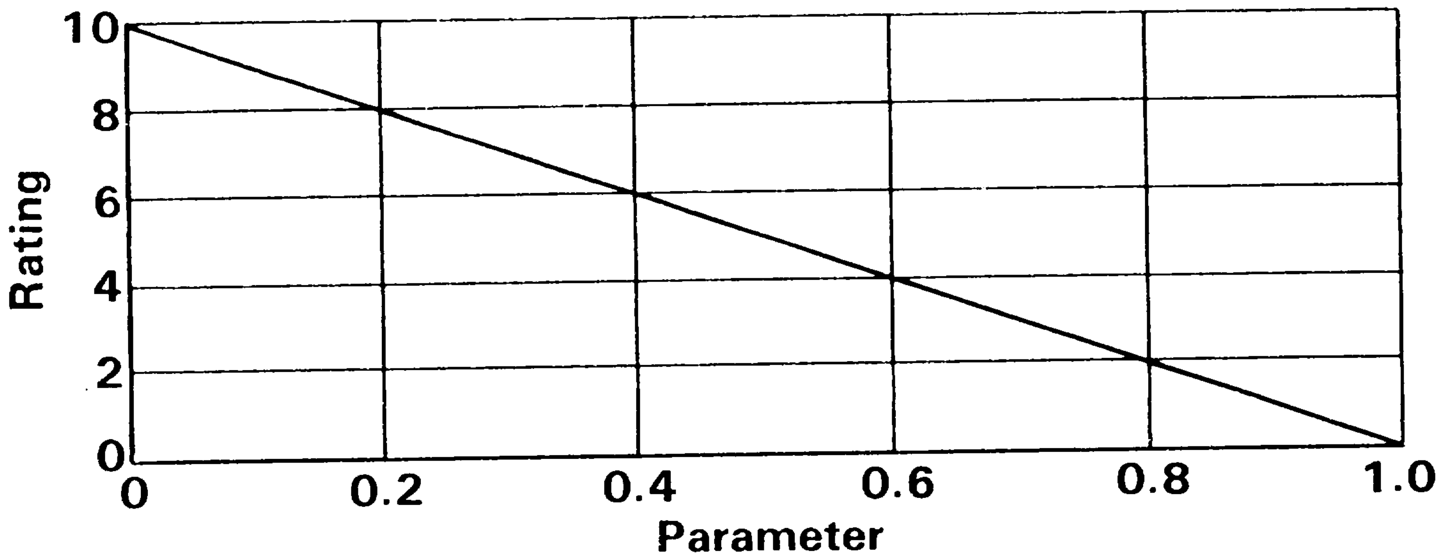
The maintainability rating is determined qualitatively by dividing operability into six sub-areas and weighting each area as follows:

Complexity of Maintenance/Servicing	4 points
Average Downtime for Servicing	2 points
Frequency of Unscheduled Downtimes	4 points
	10 points

The operability rating is determined qualitatively by dividing operability into six sub-areas and weighting each area as follows:

Startup	1 point
Checkout	2 points
Egress/Ingress	1 point
Shutdown	1 point
Recharge/Regeneration	3 points
Operational Variations During EVA	2 points
	10 points

RATING SCALES



Parameter End Point

EVA Vol	0 Rating =	$3.5\ Ft^3$
Veh Wt		6500 Lb
Pack Wt		150 Lb
Veh Vol		$400\ Ft^3$
Cost		\$3,000,000 Non Recurring & \$1,000,000 for Recurring
Reliability		10 Component Failures

ECWS LIFE SUPPORT SUBSYSTEMS

- O_2 Supply
- CO_2 Control
- Thermal Control
- Condensate Management

O_2 SUPPLY

O_2 supply concepts were presented and evaluated in the Background Experience Report (BER) HSER 7200, December 1977. As reported, there are three basic concepts for supplying EVA O_2:

- High pressure gas storage in the EVA LSS
- Chlorate candles in the EVA LSS
- Electrolysis of water in the EVA LSS

The conclusions from the BER and the ECWS sensitivity analysis are:

- Best EVA Primary O_2 system is 3000 psi GOX
- Best vehicle supply is 3000 psi electrolysis
- 900 psi GOX from vehicle Cryo supply should be considered for near term
- 6000 psi GOX is best emergency O_2 supply (Not refillable in orbit)

OXYGEN SUPPLY EVALUATION

Subsystem	Go/No-Go				Primary						Secondary					
	Performance	Safety	Availability	Acceptability	Vehicle Weight	Pack Volume	Reliability	Cost	Flexibility	Summary	Vehicle Volume	Pack Weight	Interface Compt.	Maintainability	Operability	Summary
900 psi (Cryogenic)	G	G	G	G	9.0	8.9	8	9.6	9	44.5	9.0	9.6	8	9	9	44.6
3000 psi (Vehicle Electrolysis)	G	G	G	G	9.8	9.7	8	9.6	9	46.1	9.5	9.7	8	9	9	45.2
6000 psi (High Pressure Tank Farm)	G	G	G	G	8.1	9.8	8	9.7	9	44.6	9.3	9.6	8	9	9	44.9
Clorate Candles	G	G	G	G	6.2	7.9	7	6.6	7	34.7	9.2	9.0	7.5	8	8	41.7
Electrolysis (EVA LSS)	G	G	G	G	9.0	7.2	4	4.5	9	33.7	9.5	7.3	7.5	7	6	37.3
EDO					0.3	0.3	0.15	0.1	0.15		0.3	0.2	0.1	0.2	0.2	
900 psi	G	G	G	G	2.7	2.7	1.2	1.0	1.4	9.0	2.7	1.9	0.8	1.8	1.8	9.0[1]
3000 psi	G	G	G	G	2.7	2.9	1.2	1.0	1.4	9.2	2.8	1.9	0.8	1.8	1.8	9.1
6000 psi	G	G	G	G	2.4	2.9	1.2	1.0	1.4	8.9	2.7	1.9	0.8	1.8	1.8	9.0
FFM					0.3	0.2	0.1	0.2	0.2		0.3	0.2	0.1	0.2	0.2	
900 psi	G	G	G	G	2.7	1.8	0.8	1.9	1.8	9.0	2.7	1.9	0.8	1.8	1.8	9.0
3000 psi	G	G	G	G	2.7	1.9	0.8	1.9	1.8	9.1	2.9	1.9	0.8	1.8	1.8	9.2
6000 psi	G	G	G	G	2.4	2.0	0.8	1.9	1.8	8.9	2.8	1.9	0.8	1.8	1.8	9.1
SS					0.3	0.1	0.2	0.2	0.2		0.2	0.2	0.1	0.2	0.2	
900 psi	G	G	G	G	2.7	0.9	1.6	1.9	1.8	8.9	1.8	1.9	0.8	1.8	1.8	8.1
3000 psi	G	G	G	G	2.7	1.0	1.6	1.9	1.8	9.0	1.9	1.9	0.8	1.8	1.8	8.2
6000 psi	G	G	G	G	2.4	1.0	1.6	1.9	1.8	8.7	1.8	1.9	0.8	1.8	1.8	8.1
LSC					0.1	0.1	0.4	0.3[2]	0.1		0.2	0.3	0.1	0.3	0.1[3]	
900 psi	G	G	G	G	0.9	0.9	3.2	2.7	0.9	8.6	1.8	2.9	0.8	2.7	1.9	10.1
3000 psi	G	G	G	G	0.9	1.0	3.2	2.7	0.9	8.7	1.9	2.9	0.8	2.7	1.9	10.2
6000 psi	G	G	G	G	0.8	1.0	3.2	2.7	0.9	8.6	1.8	2.8	0.8	2.7	1.9	10

(3) Cost

(2) Operability

(1) 3000 psi is Optimum for 77EVA's in 90 Days – Advantage Goes Toward 900 psi (0.1 RYD) for Fewer EVA's (51 EVA's in 60 Day EDO Mission)

HIGH PRESSURE STORAGE

Three pressure levels were evaluated for high pressure storage:

a. 900 psi
b. 3000 psi
c. 6000 psi

All pressure levels use the schematic shown.

Selection of the optimum pressure has vehicle and EVA ramifications as shown in the following figures. Specific points are:

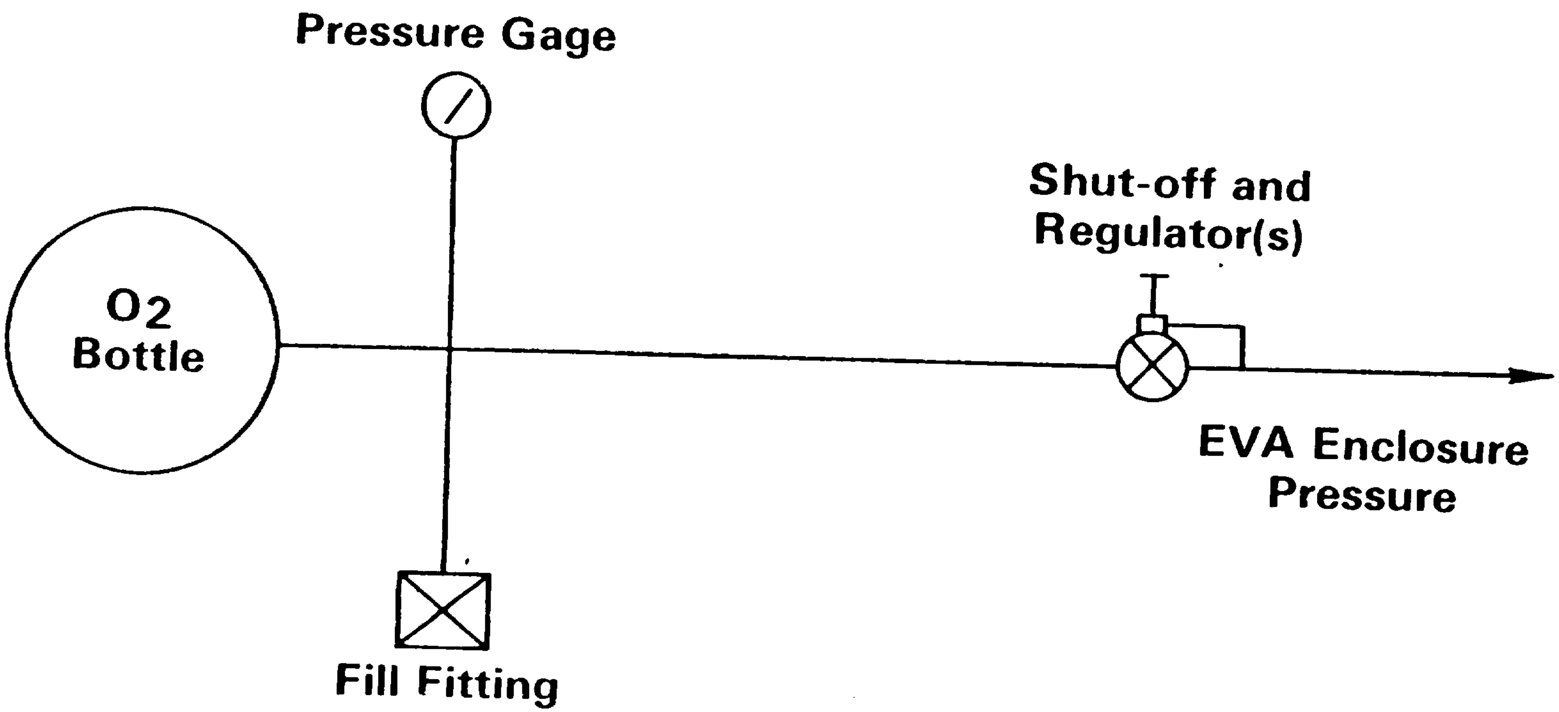
- 300 psi GOX from vehicle electrolysis is significantly lighter and smaller than vehicle GOX stored in tanks at 3000 psi or at 6000 psi. This is the recommended vehicle supply for mission lengths over 60 days.

- 3000 psi GOX is the minimum weight EVA approach, and is near minimum in volume. This is the recommended EVA Primary O_2 system.

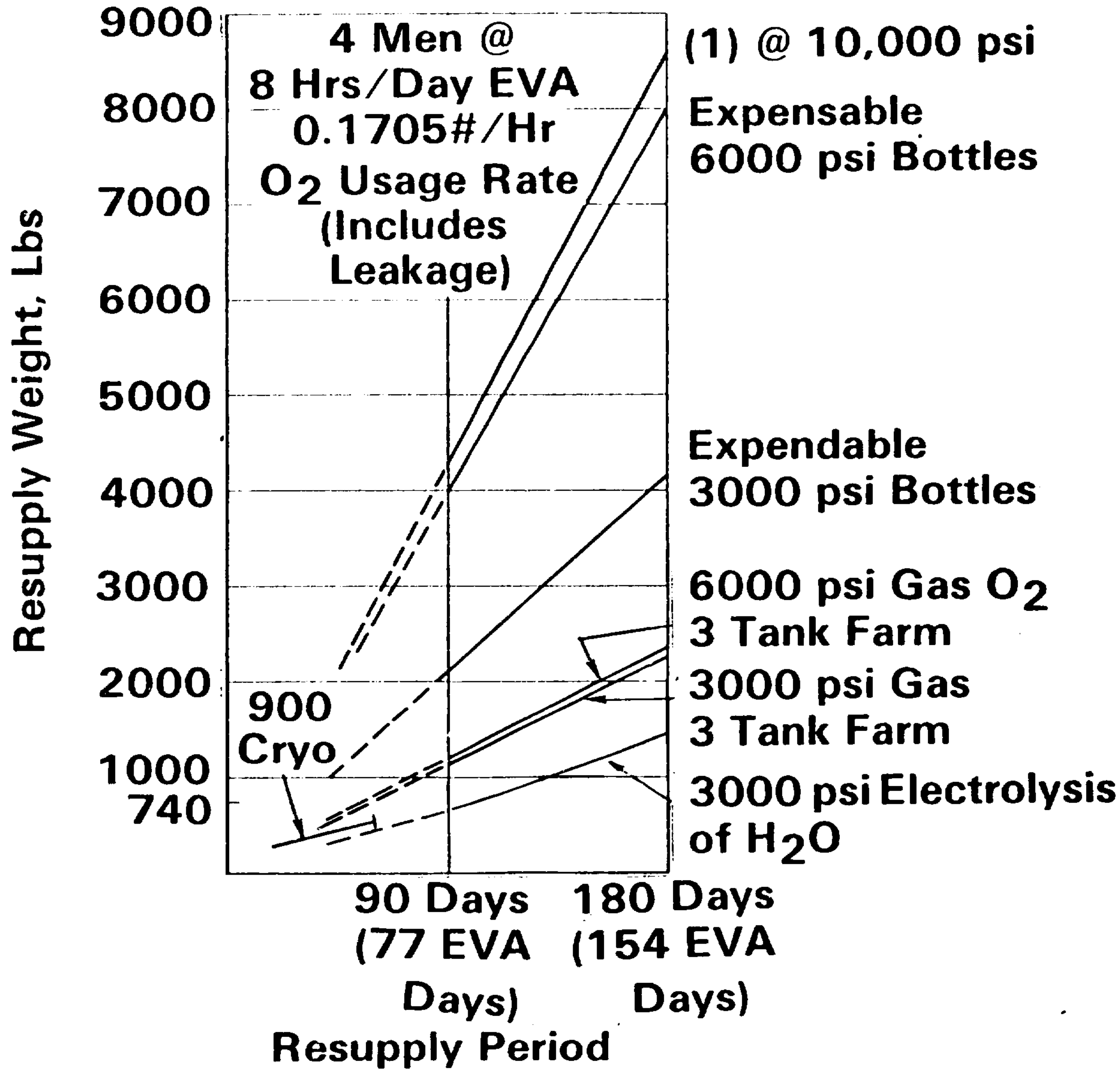
- 6000 psi GOX is the minimum volume EVA system, and is the recommended EVA secondary O_2 system, not to be recharged in orbit.

- 900 psi GOX will be available for missions up to 60 days, as limited by cryo tank insulation. This is the present Shuttle approach. This approach represents near minimum vehicle weight and volume for the 60 day mission, although it is significantly larger and somewhat heavier in the EVA LSS. It should be considered for the ECWS use missions that do not exceed 60 days.

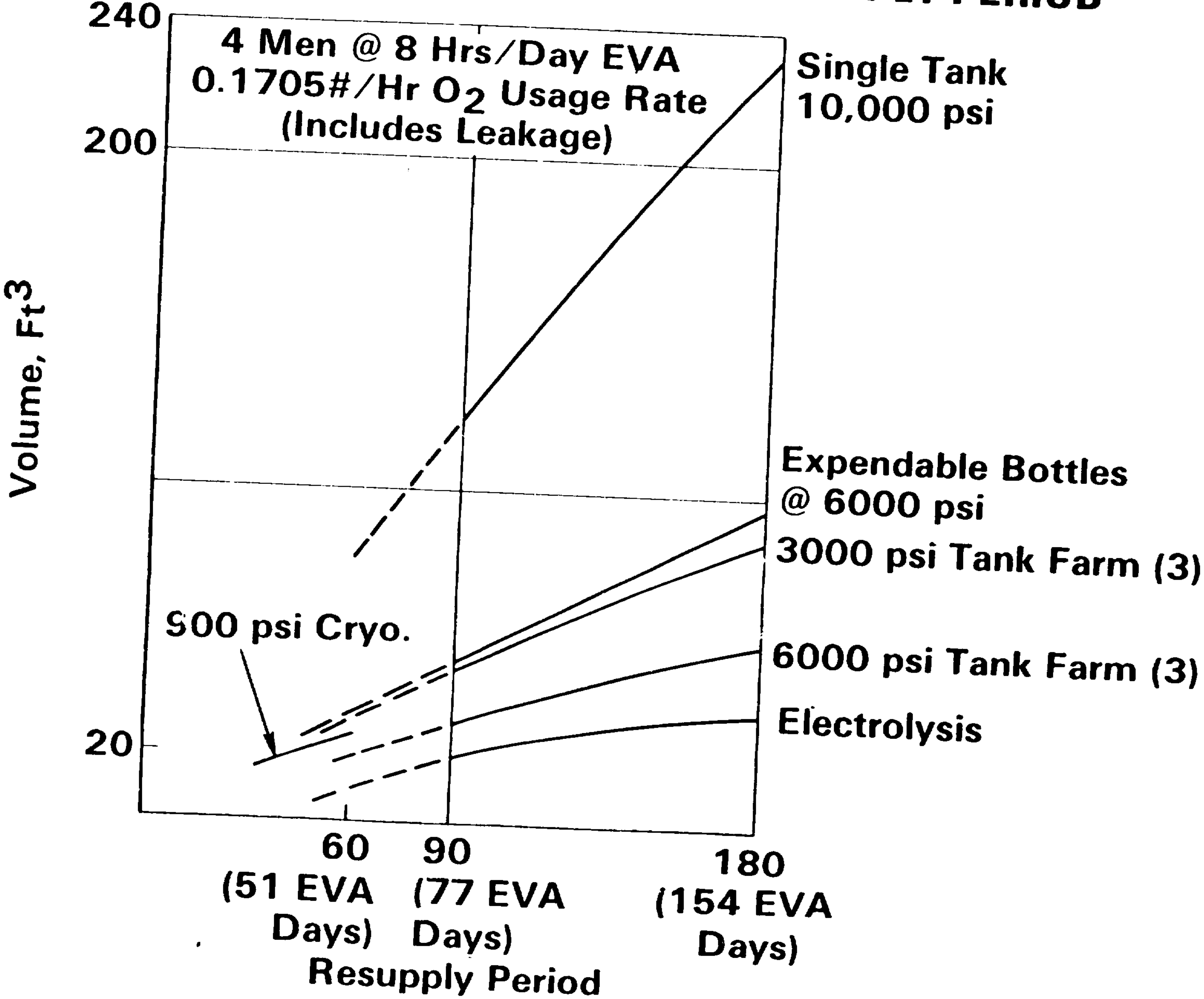
HIGH PRESSURE GAS O_2 SUPPLY



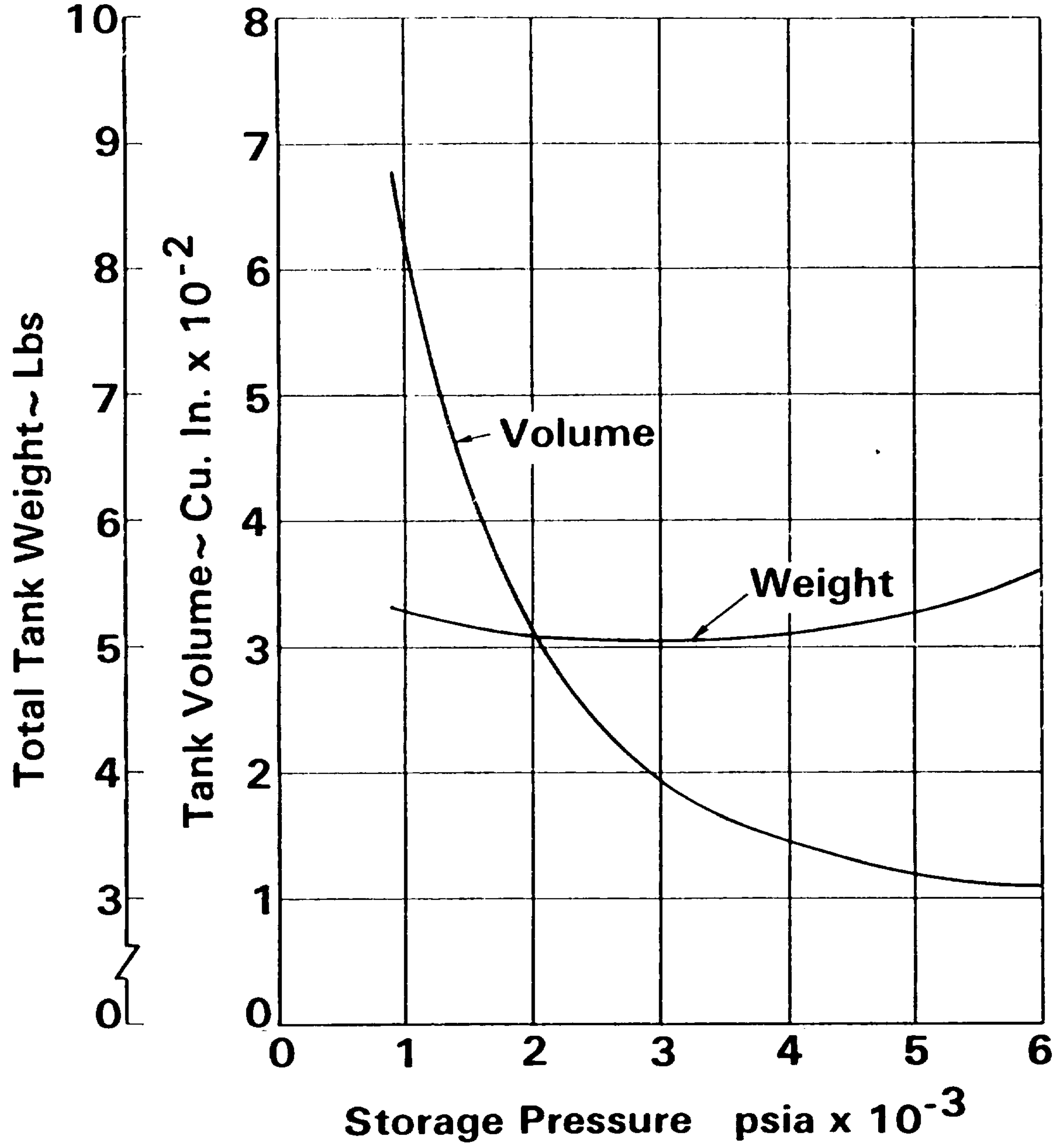
VEHICLE O_2 RESUPPLY WEIGHT VS. RESUPPLY PERIOD



VEHICLE O_2 RESUPPLY VOLUME VS. RESUPPLY PERIOD



EVA OXYGEN STORAGE PRESSURE VS. EVA WEIGHT & VOLUME



CHLORATE CANDLES

Sodium chlorate breaks down when ignited into NaCl and oxygen as shown by the following equation:

$$NaClO_3 \longrightarrow NaCl + 3/2\ O_2 + Q$$

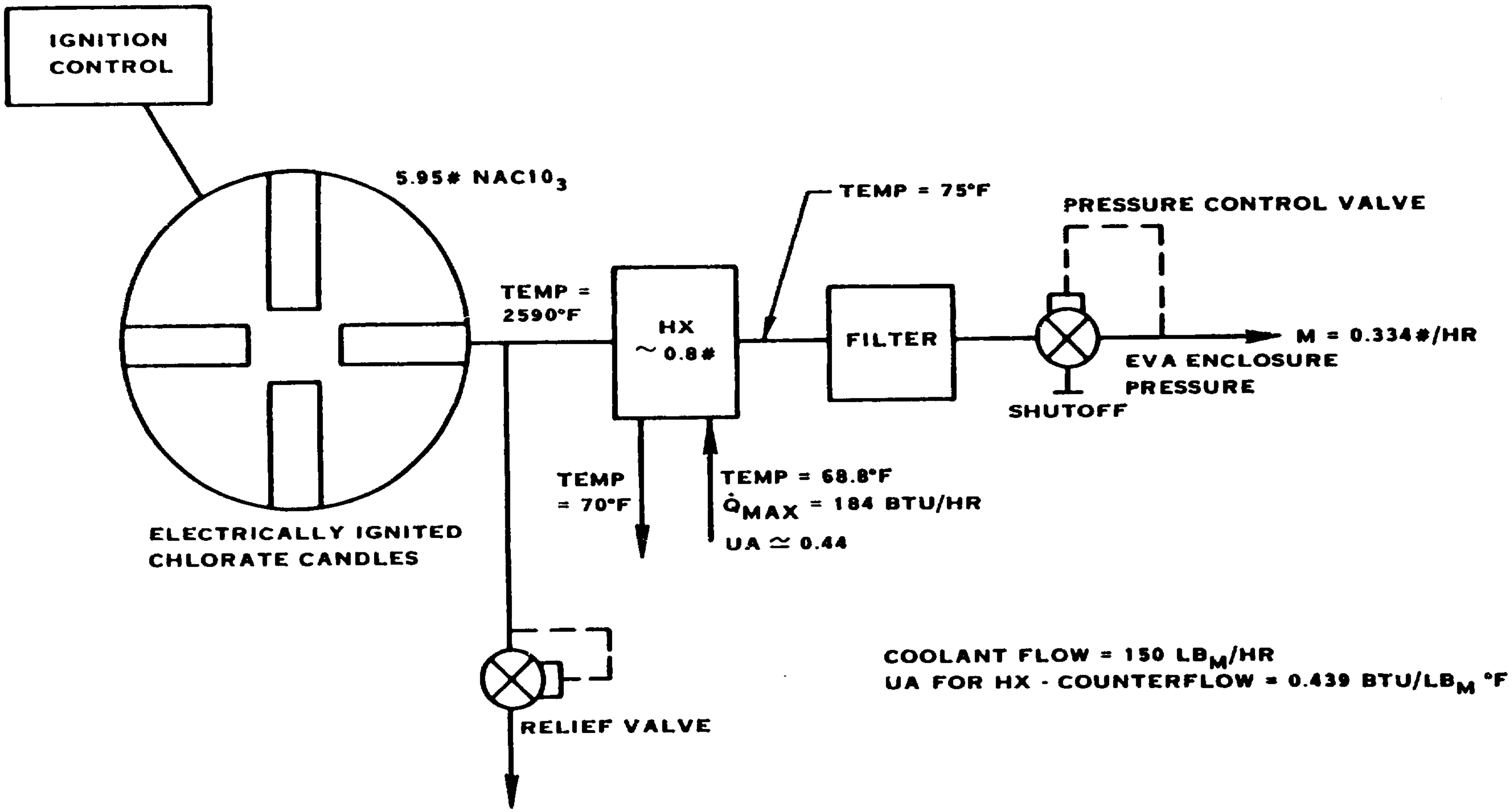
Sodium chlorate is very stable and can be stored for long periods. It is used by the Navy as an auxiliary oxygen supply for submarines. A schematic of the subsystem is shown in the opposite figure. The candles are electrically ignited and supply oxygen at a given rate, hence they have little flexibility. They produce oxygen at a given rate. Each candle is sized to provide oxygen at the maximum metabolic rate. The pressure vessel that contains the candle acts as an accumulator for overproduction during periods of below maximum metabolic activity. A filter is used to ensure delivery of pure oxygen.

The chlorate candles require the heaviest resupply, 1833 lbs, because the oxygen rate is fixed at the maximum use rate. The shape of the cartridge, required to obtain the desired oxygen rate, is very difficult to package - the candle is very long and thin. This concept is also less reliable than the high pressure gas systems as it has more components and interfaces.

SODIUM CHLORATE CANDLE FOR O_2 SUPPLY

$$NAClO_3 \longrightarrow NACl + \frac{3}{2}\,O_2 + \text{HEAT}$$

$$552\ \frac{\text{BTU}}{\#O_2\ \text{PRODUCED}} \qquad 2.22\ \frac{\#NAClO_3}{\#O_2}$$

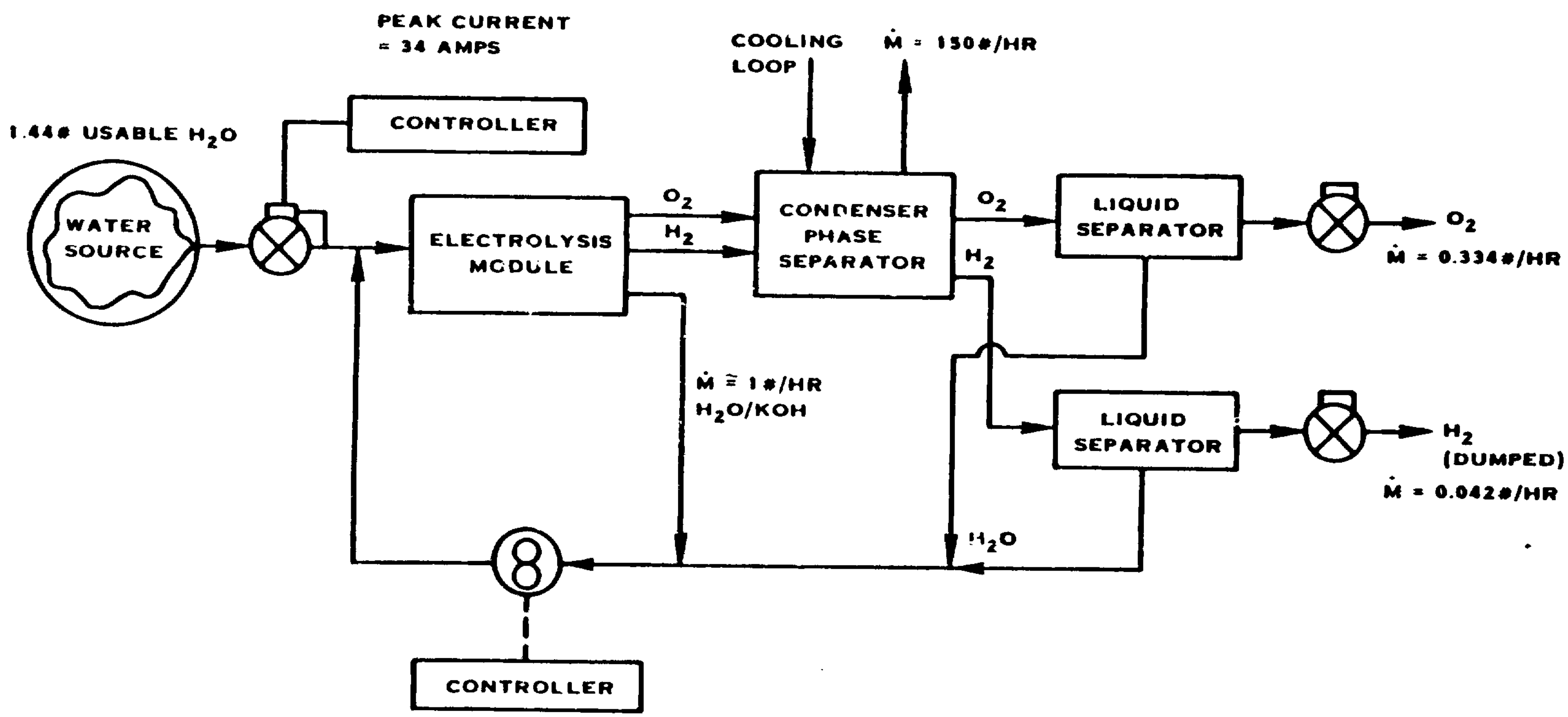


EVA ELECTROLYSIS

It is possible to electrolyze water in the EVA LSS rather than the vehicle. A schematic of an electrolysis system is shown in the accompanying figure. Water is fed from a pressurized water tank to the electrolysis cells. The oxygen and hydrogen streams leaving the cells are cooled to a low dew point, to condense the water vapor in the streams. The condensed water is then separated from the gas streams and fed back to the electrolysis modules. The hydrogen is dumped to space and the oxygen is sent to the ventilation loop.

The electrolysis cell in the EVA LSS has the same resupply weight and volume as the vehicle electrolysis system. It requires a large pack volume, is relatively low in reliability due to the large number of parts, and is the most expensive of the concepts considered. It is the lowest in both primary and secondary ratings.

EVA WATER ELECTROLYSIS



CO_2 REMOVAL

CO_2 removal concepts were presented and evaluated in the Background Experience Report (BER), HSER 7200, December 1977 and in the New Technology Identification Study No. 6 Regenerable CO_2 Removal, March 1978. An additional concept, an Electrochemically Regenerated CO_2 Absorber, is also included in this evaluation. In all, there are eight basic concepts for removing CO_2.

- LiOH
- K_2CO_3 membrane
- Solid Sorbents (ZnO, AgO)
- Li_2O_2
- Molecular Sieve
- Solid Amine
- Hydrogen Depolarized Cell (HDC)
- Electrochemically Regenerated CO_2 Absorber (ERCA)

EVA and vehicle weights and volume are as follows:

	EVA (1)		Vehicle (2)	
	Vol ft^3	Wt lbs	Vol ft^3	Wt lbs
LiOH	0.22	7.11	269	2956
K_2CO_3 Membrane	0.97	21.03	0	0
Solid Sorbents (3)	0.31	20.75	25	854
Li_2O_2	0.15	4.25	108	2017
Molecular Sieve (3) (4)	1.16	37.4	0	0
Solid Amine (4)	3.4	92.0	0	0
HDC	2.26	84.68	25	800
ERCA	0.45	39	15	(376) (5)

(1) Based on CO_2 pp of 15 mm Hg and flow rate of 4.0 lb/hr
(2) Based on 90-day resupply
(3) Requires 300 watts for 4 to 6 hours per day
(4) Does not include O_2 ullage in canister lost overbaord during the desorb cycle
(5) Concept returns CO_2 to vehicle for reduction, thus saving vehicle resupply H_2O. Water resupply credit becomes available when CO_2 reduction become available.

CO_2 REMOVAL (Continued)

The conclusions from the BER and ECWS sensitivity analysis are:

- LiOH is the best near term choice
- K_2CO_3 membrane approach appears to be the best overall long term choice
- Metal oxides should be pursued if the need arises in the future to reclaim EVA CO_2.

CO_2 CONTROL EVALUATION

Subsystem	Go/No-Go				Primary						Secondary					
	Performance	Safety	Availability	Acceptability	Vehicle Weight	Pack Volume	Reliability	Cost	Flexibility	Summary	Vehicle Volume	Pack Weight	Interface Compt.	Maintainability	Operability	Summary
LiOH	G	G	G	G	5.5	9.5	10	7.2	8	40.2	5.5	9.8	9	8	9	41.3
Li_2O_2	G	G	G	G	5.9	9.6	8	2.6	7	33.1	7.2	9.9	9	8	8	42.1
Solid Amine	G	G	G	G	10	0.2	6	3	9	28.2	9.4	10	8	6	7	40.4
Molecular Sieve	G	G	G	G	10	6.6	6	3	9	34.6	10	10	8	6	7	41.0
Solid Sorbents	G	G	N	G	8.6	9.2	10	1	8	36.8	10	9.4	8	7	7	41.9
HDC	G	G	G	G	10	3.4	6	3	8	30.4	10	10	8	5	6	39
K_2CO_3 Membrane	G	G	N	G	10	7.2	8	3	10	38.2	10	10	10	8	10	48.0
ECRA-Veh. Regen.	G	G	N	G	10.5	9.2	2	-4	10	27.7	9.6	7.4	5	3	5	30
EDO					0.3	0.3	0.15	0.1	0.15		0.3	0.2	0.1	0.2	0.2	
LiOH	G	G	G	G	1.7	2.9	1.5	0.7	1.2	8.0	1.7	2.0	0.9	1.6	1.8	8.0
Solid Sorbents	G	G	G	G	2.6	2.8	1.5	0.1	1.2	8.2	3.0	1.9	0.8	1.4	1.6	8.7
K_2CO_3	G	G	N	G	3.0	2.2	1.2	0.3	1.5	8.2	3.0	2.0	1.0	1.6	2.0	9.6
FFM					0.3	0.2	0.1	0.2	0.2		0.3	0.2	0.1	0.2	0.2	
LiOH	G	G	G	G	1.7	1.9	1.0	1.4	1.6	7.6	1.7	2.0	0.9	1.6	1.8	8.0
Solid Sorbents	G	G	G	G	2.6	1.8	1.0	0.2	1.6	7.2	3.0	1.9	0.8	1.4	1.6	8.7
K_2CO_3	G	G	G	G	3.0	1.4	0.8	0.6	2.0	7.8	3.0	2.0	1.0	1.6	2.0	9.6
SS					0.3	0.1	0.2	0.2	0.2		0.2	0.2	0.1	0.3	0.2	
LiOH					1.7	1.0	2.0	1.4	1.6	7.7	1.1	2.0	0.9	2.4	1.8	8.2
Solid Sorbents	G	G	G	G	2.7	0.9	2.0	0.2	1.6	7.4	2.0	1.9	0.8	2.1	1.6	8.4
K_2CO_3	G	G	G	G	3.0	0.7	1.6	0.6	2.0	7.9	2.0	2.0	1.0	2.4	2.0	9.4
LSC					0.1	0.1	0.4	0.3 (1)	0.1		0.2	0.3	0.1	0.3	0.1 (2)	
LiOH	G	G	G	G	0.6	1.0	4.0	2.7	0.8	9.1	1.1	2.9	0.9	2.4	0.1	7.4
Solid Sorbents	G	G	G	G	0.9	0.9	4.0	2.4	0.8	9.0	2.0	2.8	0.8	2.1	0.1	7.8
K_2CO_3	G	G	G	G	1.0	1.0	3.2	3.0	1.0	8.7	2.0	3.0	1.0	2.4	0.3	8.7

(1) Operability
(2) Cost

LiOH

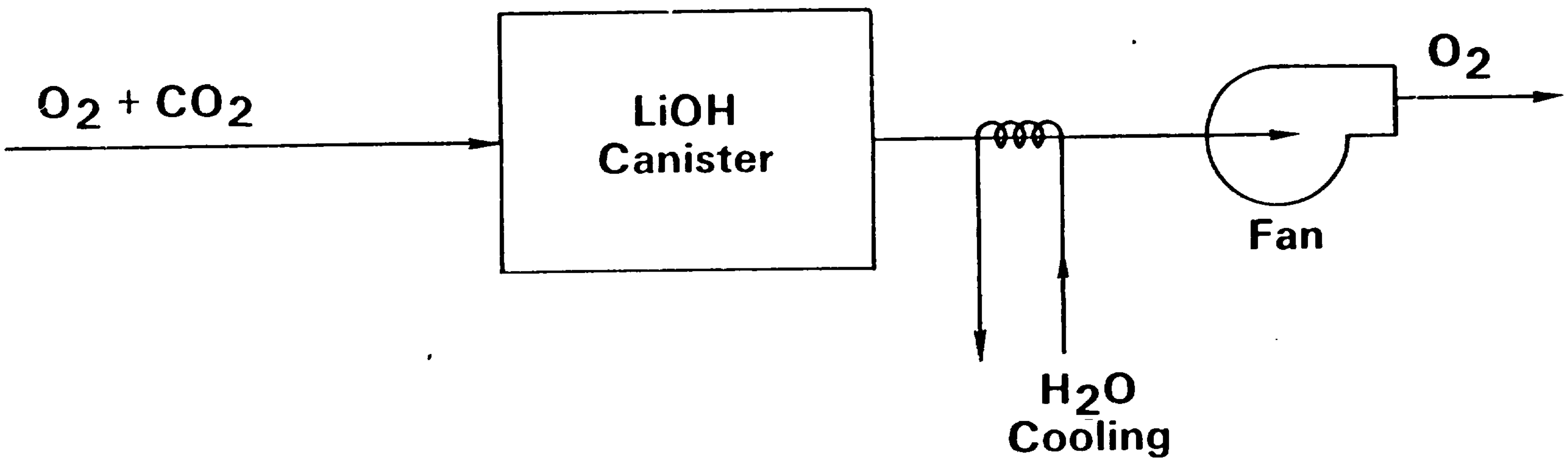
LiOH Lithium Hydroxide (LiOH) is used to remove carbon dioxide for the present Shuttle EMU. A schematic of the concept is shown in the opposite figure. The overall chemical reaction is:

$$2\ LiOH + CO_2 \longrightarrow Li_2CO_3 + H_2O + Q$$

The LiOH is a porous granular material which is packed into a bed. Gas flow through the bed carries away the heat generated by the reaction of CO_2 with the chemical. Liquid cooling of the bed can be used to reduce the fan inlet temperature and, therefore, to reduce the volume flow rate and power.

LiOH has the highest rating of the available concepts, and therefore is recommended for the near term. However, for the far term, its vehicle resupply weight of 2956 lbs and 169 ft^3 resupply volume for 308 EVA sorties make LiOH unattractive with respect to the regenerable CO_2 concepts. The regenerable concepts require technology development, and hence, are not available in the near term.

LiOH CO_2 REMOVAL NON-REGENERABLE



K_2CO_3 MEMBRANE

The fundamental liquid CO_2 sorbent concept technology is already in use in the industrial "hot pot" K_2CO_3 process of the natural gas industry, used to remove unwanted CO_2 from pipe line gas. In that application the process runs at 230°F under several hundred pounds pressure.

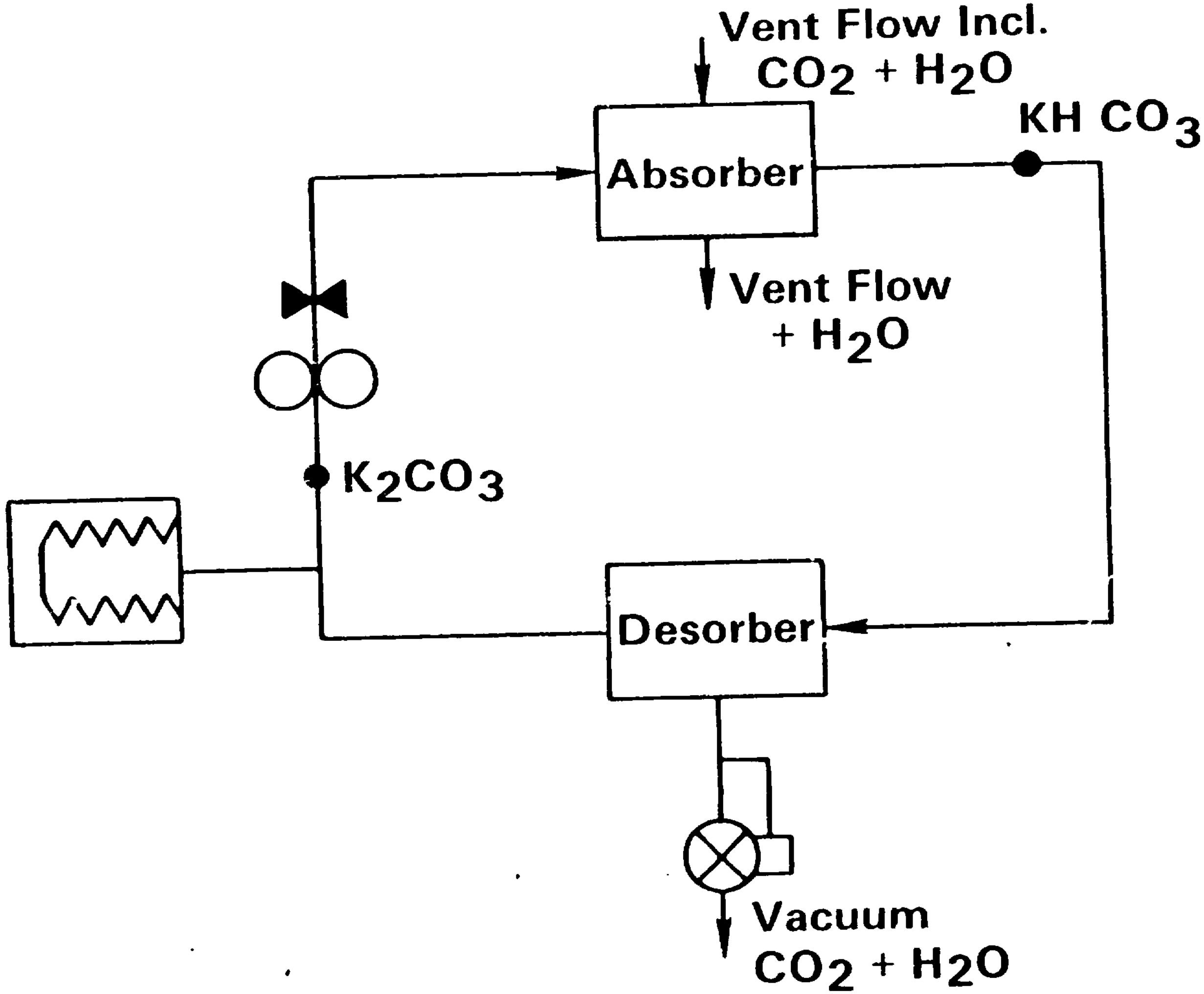
The accompanying illustration shows a schematic of the liquid sorbent concept adapted for EVA use. The concept consists of the K_2CO_3 transport loop, an absorber and a desorber, a pump and accumulator, and a back pressure regulator. A liquid solution of potassium carbonate (K_2CO_3) enters the absorber unit. Metabolically produced CO_2 and water also enter the absorber via the vent gas stream. A membrane separates the gas and liquid flow streams. The membrane also permits CO_2 to diffuse from the vent flow streams into the liquid stream. The CO_2 and water are reacted by the following equation:

$$K_2CO_3 + H_2O + CO_2 \longrightarrow 2KHCO_3 + Q$$

The solution is then pumped to the desorber unit which also uses a membrane. The low pressure reverses the reaction, rejecting the CO_2 to vacuum along with some water vapor. The evaporation of water cools the liquid flow stream. While the system relies on water loss to operate, the amount of water lost is more than offset by the metabolic condensate produced over the range of 400 to 2000 Btu/hr. It is expected that the water loss incurred by the K_2CO_3 process will serve to reduce the condensate storage requirement of the ECWS LSS. A pressure regulator controls the gas pressure outside the membrane to a low enough level to permit CO_2 diffusion, but high enough to prevent freezing and to limit evaporating of water.

New technology is required to develop membranes. This system, with low resistance membranes, is potentially very small and light. This system was dropped from the near term consideration as suitable membranes have yet to be found. It is believed that with technology development, suitable membranes can be found. On this basis an ECWS LSS CO_2 removal subsystem was sized, resulting in a weight of 21 lbs. Since this concept regulates continuously in use, no regenerating equipment is needed in the vehicle. There are no expendables associated with this concept. A potential disadvantage is that all EVA-produced CO_2 is lost, preventing reclamation of its O_2 in the vehicle.

LIQUID SORBENT REGENERABLE CO_2 REMOVAL SUBSYSTEM SCHEMATIC



SOLID SORBENTS

Solid sorbents,typified by metallic oxides such as ZnO, and Ag_2O react with CO_2 according to the following reversible reaction:

$$MO + CO_2 \longrightarrow M\,CO_3 + Q$$

As shown in the accompanying figure, the carbonate readily decomposes with increasing temperature.

There are two problems that must be solved in future development to make this approach achieve potential utility to ECWS:

1) Physical Stability
2) High Surface Area

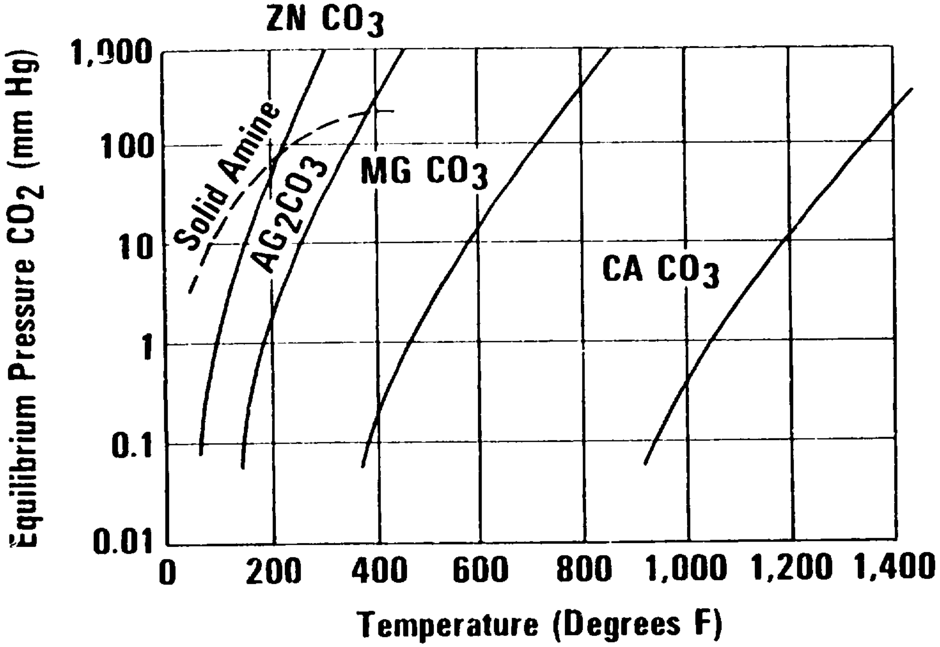
Excessive volume change during the adsorb/desorb cycle affects the chemicals physical stability. It has been assumed for the analyses in this report that 10 adsorb/desorb cycles are possible. Increasing the stability will increase the life of each cartridge, and will reduce vehicle weight and volume penalties. Doubling the cycle life to 20 would reduce vehicle resupply weight by 427 lbs, and would save 12 ft^3 of volume.

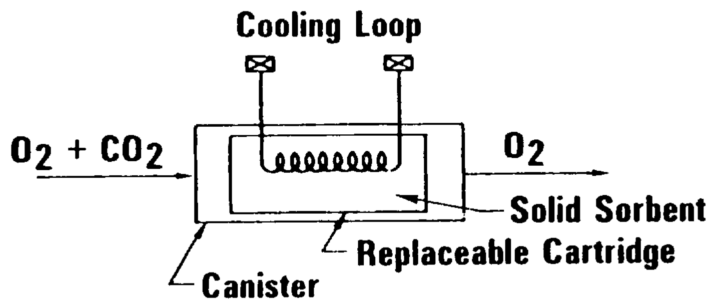
With low surface areas, not all of the solid sorbent oxide can react at a high enough rate to be useful. Utilizations as high as 30 percent of theoretical have been obtained. It has been assumed that 50 percent utilization will be possible with further development.

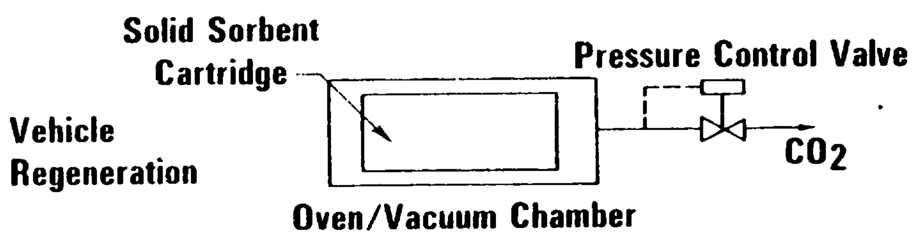
In the vehicle regeneration configuration, the adsorbent is packaged in a cartridge which is regenerated after each mission. An oven/vacuum chamber will be provided in the vehicle for cartridge regeneration.

Should future vehicle $H_2/O_2/H_2O$ balance require reduction of EVA-generated CO_2, then the solid sorbent concepts become the recommended EVA CO_2 removal concept. The trade study reflects a credit for reduction of EVA CO_2 for future missions phases. This study analysis assumes CO_2 reduction will become available with Space Station. Credit for O_2 reclaimed by reducing EVA CO_2 is expressed in savings of water to be electrolysed to generate equivalent O_2.

SOLID SORBENTS







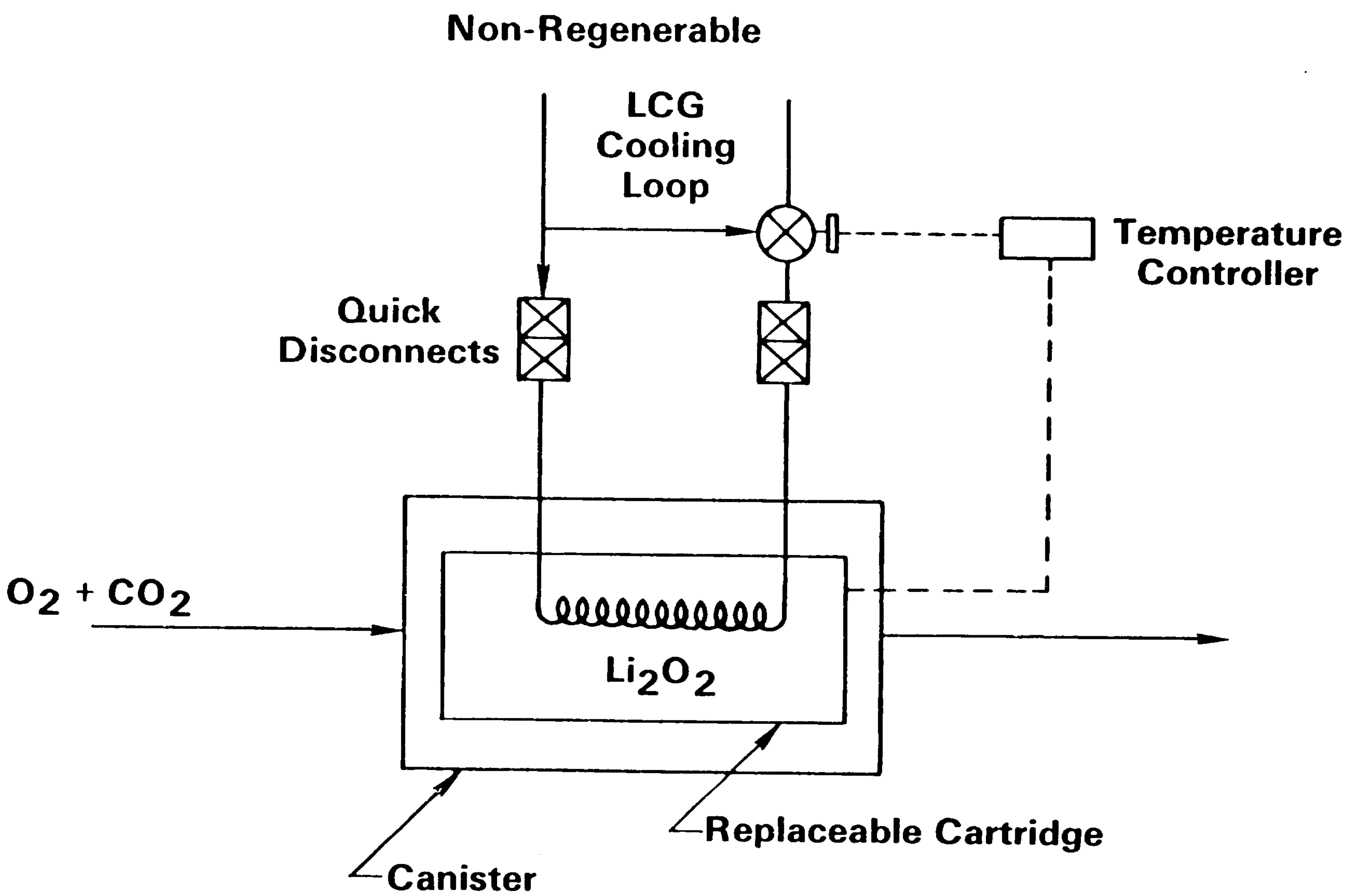
Li_2O_2

Lithium Peroxide (Li_2O_2) is another porous granular chemical that reacts with CO_2. It also produces some oxygen. The overall chemical reaction is:

$$Li_2O_2 + CO_2 \qquad Li_2CO_3 + 1/2\ O_2 + Q$$

Li_2O_2 produces much more heat than LiOH. The rate at which the oxygen is evolved is a function of the bed temperature. The higher the temperature the faster the oxygen production rate. The rate of CO_2 removal is also a function of the temperature. The higher the temperature, the slower the rate of removal. In order to control the oxygen generation rate and the CO_2 removal rate, a water cooling circuit is used to control the bed temperature. Catalysts are used to promote the oxygen generation. The chemical does not produce enough oxygen to meet the breathing requirement; so additional oxygen storage is required. More development is required to make the system work at the desired rates over all inlet gas conditions. A schematic of the system is shown in the accompanying figure. The low rating of this concept is due primarily to the vehicle weight and volume resupply penalties, for like LiOH, Li_2O_2 is not a regenerable concept.

Li_2O_2 CO_2 REMOVAL

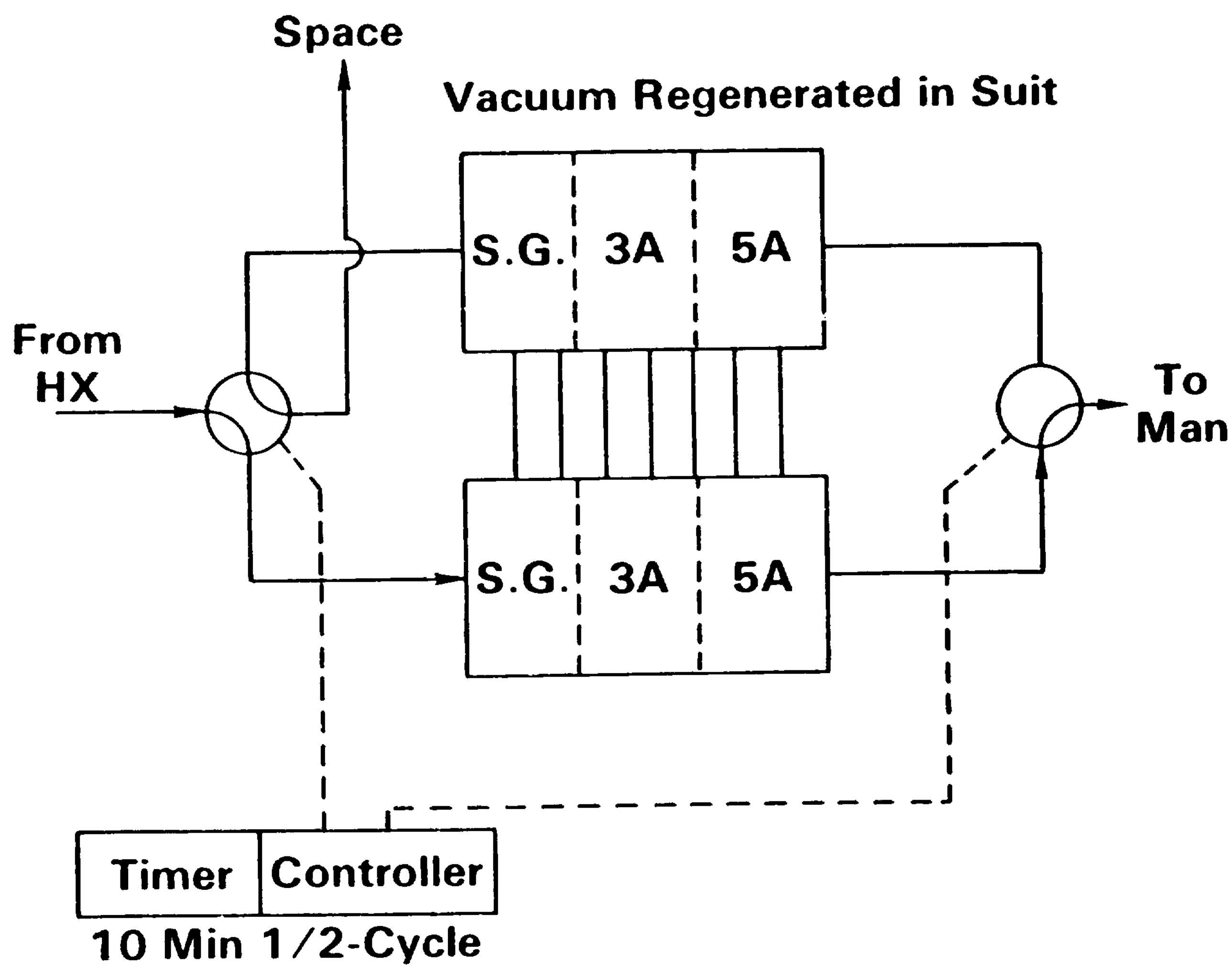


MOLECULAR SIEVE

The molecular sieve is a regenerable CO_2 and humidity control system. A schematic of the system is shown in the accompanying figure. Molecular sieve material is a zeolite which has a crystalline structure which contains many interconnecting cavities, all of uniform size. These large surface area cavities are capable of absorbing many different gases and liquids, especially polar molecules such as CO_2 and water. Molecular sieves will absorb water in preference to CO_2. Small amounts of absorbed water will cause a large deterioration in the ability to absorb CO_2. The CO_2 absorbing portion of the bed is, therefore, protected from water by beds of silica gel and 3A molecular sieve.

In an operational system, two beds are used. One bed absorbs CO_2 and water from the gas stream. When the bed is fully loaded, it is exposed to space vacuum and the gases are desorbed. While the first bed is desorbing, a second bed is switched into the gas stream. This system is smaller than the HS-C system as the molecular sieve material capacity for CO_2 is proportional to the partial pressure level. However, this system is considerably larger than the LiOH and solid sorbent systems, which are both single-bed systems. Its relative complexity, relative to the single bed systems, makes it relatively expensive and relatively unreliable.

MOLECULAR SIEVE SYSTEM THERMALLY COUPLED BEDS



SOLID AMINE

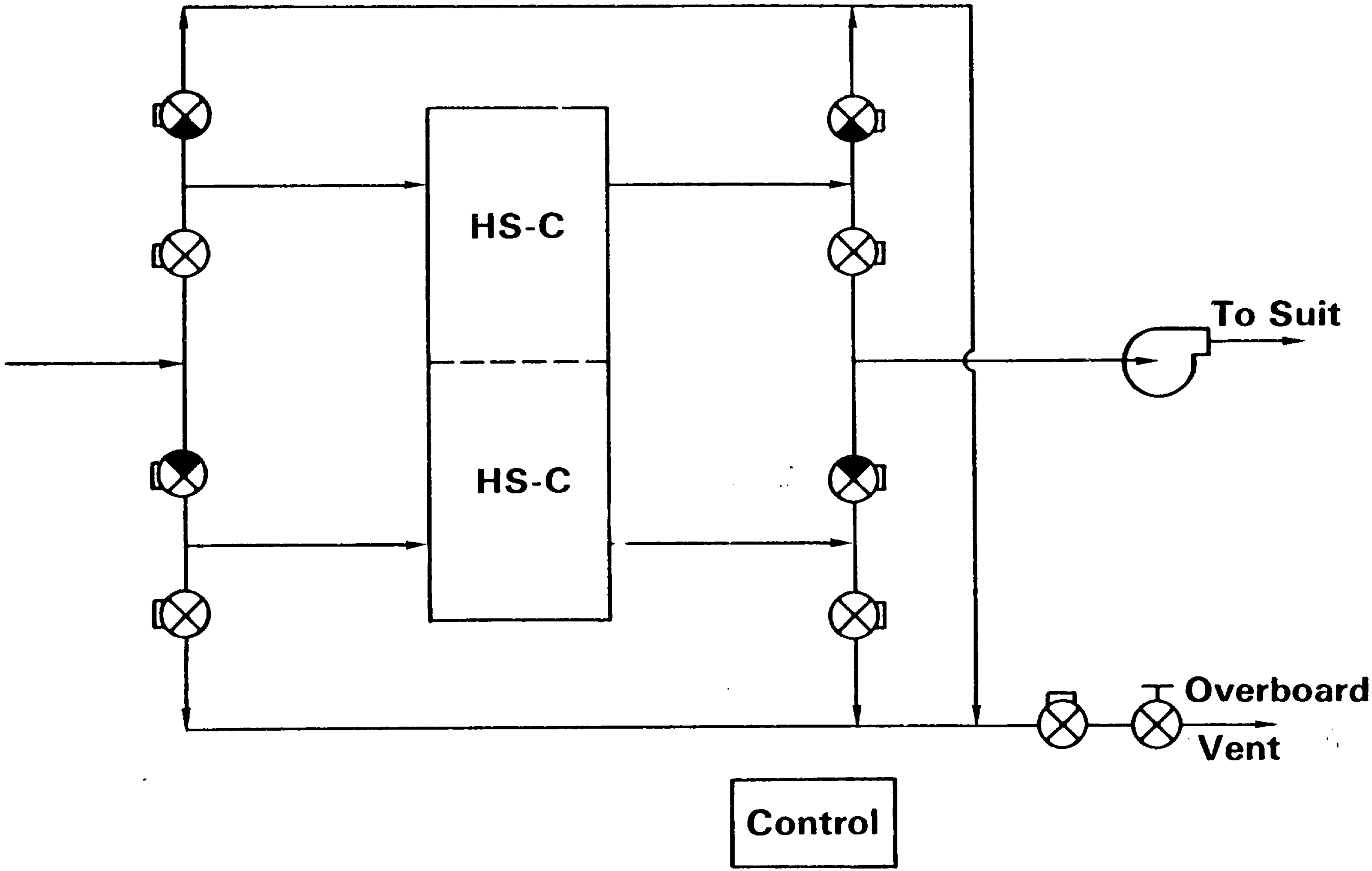
Solid Amine is a regenerable CO_2 and humidity control system. A schematic of the system is shown. A material is used to adsorb CO_2 and water vapor from the gas stream. The CO_2 and water vapor are subsequently desorbed when exposed to space vacuum. Continuous adsorption from the gas stream and desorption to space is achieved by utilizing two beds which are alternately cycled between adsorption and desorption. This system is currently being developed for potential use on the Shuttle vehicle.

The solid amine material is comprised of small, spherical, highly porous, acrylic ester pellets (0.5 mm) coated with a thick non-volatile liquid, polyethyenimine (PEI). The porous substrate exposes an extremely large surface area of the PEI coating to the gas stream. The PEI is then able to adsorb the CO_2 and water vapor from the gas stream.

As the reaction is a chemical one, there is only a slight increase in capacity for CO_2 with increasing partial pressure. As the gas loop can have high partial pressures of CO_2, the solid amine system does not become appreciably smaller because of this. This system is much larger than the other concepts, hence was eliminated from further consideration.

SOLID AMINE CO_2 REMOVAL

Thermally Coupled Beds — Vacuum Regenerated in Suit



HYDROGEN DEPOLARIZED CELL

The Hydrogen Depolarized Cell (HDC) concentrates CO_2 in a gas stream. The basic energy for the process is from the fuel cell reaction of hydrogen (H_2) and oxygen (O_2).

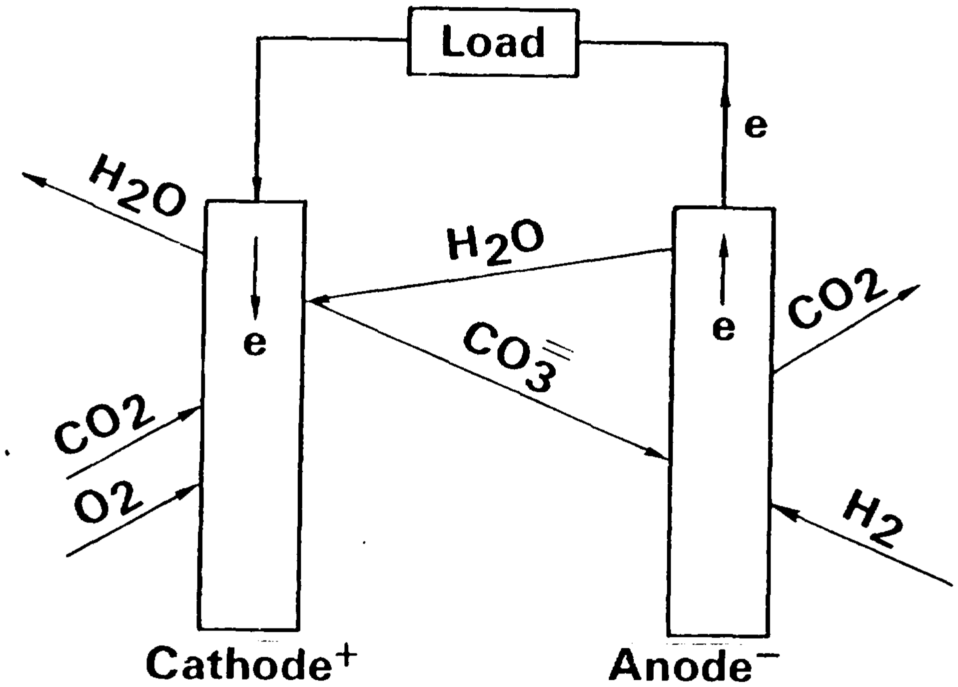
$$H_2 + 1/2\ O_2 \longrightarrow H_2O + Q$$

The electrical cell pumps CO_2 from a low partial pressure gas stream (cathode) through the electrolyte in the cell matrix to a high CO_2 partial pressure at the anode side. The reaction of the oxygen and water at the cathode forms hydroxyl ions (OH^-) which react with CO_2 in a "scrubbing" reaction to form carbonate ions ($CO_3^=$). These $CO_3^=$ and OH^- ions are transferred through the electrolyte to the anode. At the anode, the reaction of H_2 and OH^- ions forming water causes a deficiency of OH^- ions. To relieve this deficiency, the following reaction is forced:

$$CO_3^= + H_2O \longrightarrow CO_2 + 2OH^-$$

The CO_2 produced is discharged into the hydrogen stream. The water generated is evaporated into the gas stream. A schematic of the cell reactions and a schematic of the system are shown in the accompanying figures. This system is not competitive on a weight and volume basis. The stored gases (O_2 and H_2) require too large an EVA volume and the vehicle resupply weight requirements are unattractive.

HDC CELL REACTIONS



Cathode:

$$O_2 + 2\,H_2O + 4e \rightarrow 4\,OH^-$$
$$2\,CO_2 + 4OH^- \rightarrow 2\,H_2O + 2\,CO_3^{=}$$

$$O_2 + CO_2 + 4e \rightarrow 2\,CO_3^{=}$$

Anode:

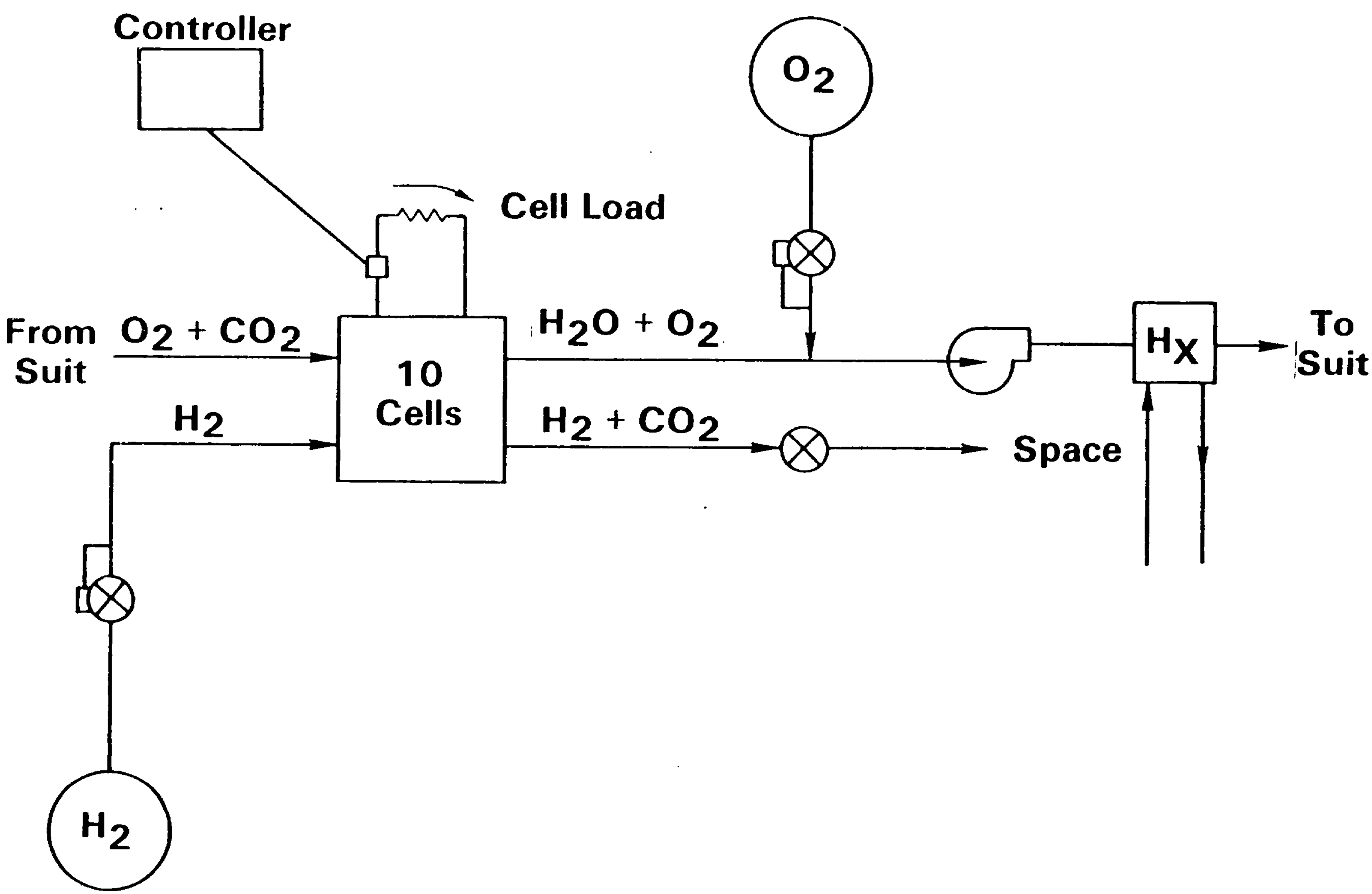
$$2\,H_2 + 4\,OH^- \rightarrow 4\,H_2O + 4e$$
$$2\,CO_3^{=} + 2\,H_2O \rightarrow 4\,OH^- + 2\,CO_2$$

$$2\,H_2 + 2\,CO_3^{=} \rightarrow 2\,H_2O + 2\,CO_2 + 4e$$

Overall:

$$2\,H \quad + O \rightarrow 2\,H_2O$$

HYDROGEN DEPOLARIZED CELL FOR CO_2 REMOVAL



ELECTROCHEMICALLY REGENERABLE CO_2 ABSORBER

(Vehicle Regenerated)

This process combines features of the $K_2\ CO_3$ liquid sorbent and the hydrogen depolarized cell processes. During EVA a hollow fiber membrane absorber removes CO_2 from the O_2 ventilation stream. The absorber has sufficient capacity to absorb all CO_2 produced during an EVA sortie.

The CO_2-laden absorbers are regenerated electrochemically in the vehicle between EVA's. The spent absorber is removed from the ECWS and connected to the regenerator. The CO_2-laden absorbent is pumped out of the absorber and is transferred to the electrochemical regenerator module. N_2 gas purges the sorbent of dissolved O_2. A subsequent H_2 purge assures H_2 contact with the electrode surfaces prior to starting the actual regeneration. Application of electric current (approximately 90 watts) causes the following reactions to occur:

<u>Cathode:</u> $2\ H_2O + 2 \rightarrow 2\ OH^- + H_2$

<u>Anode:</u> $2\ OH^- + H_2 \rightarrow 2\ H_2O = 2$

$CO_3^= + H_2O \rightarrow CO_2 + 2\ OH$

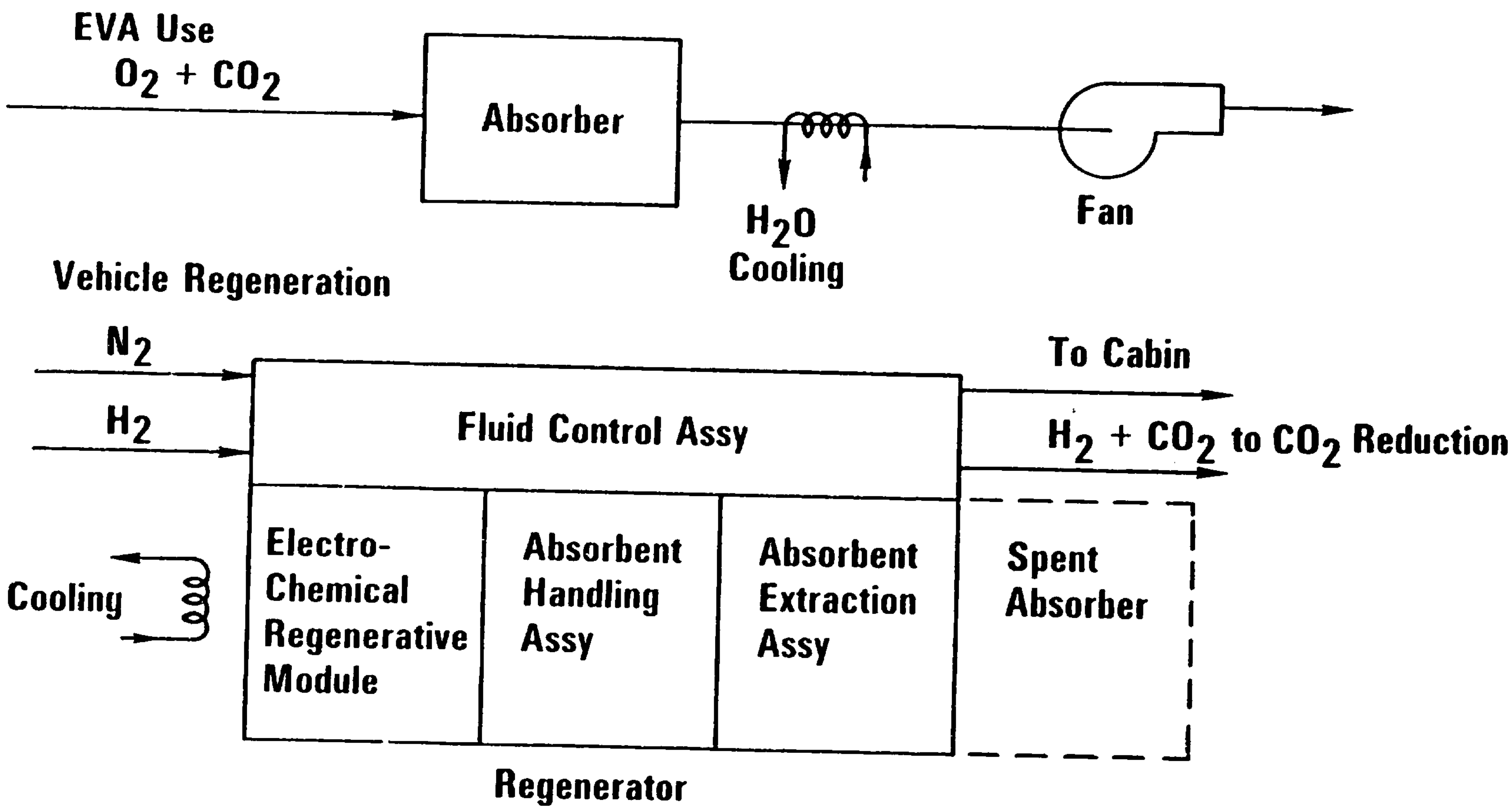
<u>Overall:</u> $CO_3 + H_2O$ + Electrical energy $\rightarrow 2\ OH^- + CO_2$ + Heat

During regeneration H_2 is fed to the regenerator to provide a mixture of H_2 and CO_2 for subsequent CO_2 reduction and production of water. Following regeneration, a final N_2 purge removes the H_2 from the regenerated sorbent. The regenerated sorbent is pumped back into the absorber, completing the regeneration process.

As with other advanced concepts, the ERCA concept requires new technology development, hence is not presently available for use. In addition, it requires an on-board vehicle CO_2 reduction facility to utilize the EVA CO_2 reclamation capability. Hence the concept becomes applicable only when CO_2 reduction becomes available. Because the concept reclaims EVA CO_2 for reduction, ERCA earns credit for reducing vehicle water resupply requirements. The concept is competitive from an EVA volume and weight viewpoint. However, the complexity of on-orbit regeneration reduces the reliability, maintainability, operability and interface ratings. The concept is also expected to be costly owing to its reliance on both membrane and electrochemistry. Although its EVA CO_2 reclamation capability is a unique attribute, the overall cost and complexity makes the concept uncompetitive with simpler concepts.

ELECTROCHEMICALLY REGENERABLE CARBON DIOXIDE ABSORBER

(Regenerated in Vehicle)



THERMAL CONTROL

Thermal control concepts were presented and evaluated in the Background Experience Report (BER), HSER 7200, December 1977 and in two New Technology Identification Studies, No. 5 Hybrid Heat Sink, February 1978, and No. 9 Heat Sink, November 1978. As reported, there are only two basic methods of thermal control:

- Phase change materials
- Radiation to Space

The conclusions from the BER and ECWS sensitivity analyses are:

- Water is the best phase change material, if available, but is expected to become unavailable at low penalty after the vehicle becomes solar powered.
- Ice is the best solid-to-liquid phase change material, but it is too bulky and heavy to be the sole thermal control means.
- Radiators, while promising, will not work in all locations, and cannot be relied upon to be the sole thermal control means.
- Hybrid and other thermal control concepts look promising.
- Significant new technology effort is required to solve the thermal control problem.

EXPENDABLE HEAT SINK EVALUATION

Subsystem	Go/No-Go				Primary						Secondary						Selection
	Performance	Safety	Availability	Acceptability	Vehicle Weight	Pack Volume	Reliability	Cost	Flexibility	Summary	Vehicle Volume	Pack Weight	Interface Compt.	Maintainability	Operability	Summary	
Sublimator	G	G	G	G	2.3	10	7	10	9	38.3	7.2	10	8	10	8	43.2	
Water Boiler	G	G	G	G	2.3	7.2	7	9	8	33.5	7.2	9.7	9	8	9	45.4	X
Flash Evaporator	G	G	G	G	2.3	9.8	7	8.5	9	36.5	2.2	9.4	6.5	8	8	34.1	
EDO					0.3	0.3	0.15	0.1	0.15		0.3	0.2	0.1	0.2	0.2		
Sublimator					0.7	3.0	1.1	1.0	1.4	7.2	2.2	2.0	0.8	2.0	1.6	8.6	
Water Boiler					0.7	2.2	1.1	0.9	1.2	6.1	2.2	1.9	0.8	1.6	1.8	8.3	X
Flash Evaporator					0.7	3.0	1.1	0.9	1.4	7.1	2.2	1.9	0.7	1.6	1.6	8.0	
FFM					0.3	0.2	0.1	0.2	0.2		0.3	0.2	0.1	0.2	0.2		
Sublimator					0.7	2.0	0.7	2.0	1.4	6.8	2.2	2.0	0.8	2.0	1.6	8.6	
Water Boiler					0.7	1.4	0.7	1.8	1.2	5.8	2.2	1.9	0.8	1.6	1.8	8.3	X
Flash Evaporator					0.7	2.0	0.7	1.7	1.4	6.5	2.2	1.9	0.7	1.6	1.6	8.0	
SS					0.3	0.1	0.2	0.2	0.2		0.2	0.2	0.1	0.3	0.2		
Sublimator					0.7	1.0	1.4	2.0	2.0	7.1	1.4	2.0	0.8	3.0	1.6	8.8	
Water Boiler					0.7	0.7	1.4	1.8	1.8	6.4	1.4	1.9	0.9	2.4	1.8	8.4	X
Flash Evaporator					0.7	1.0	1.4	1.7	1.7	6.5	1.4	1.9	0.7	2.4	1.6	8.0	
LSC					0.1	0.1	0.4	0.3[1]	0.1		0.2	0.3	0.1	0.3	0.1[2]		
Sublimator					0.2	1.0	2.8	2.4	0.8	7.2	1.4	3.0	0.8	3.0	1.0	9.2	
Water Boiler					0.2	0.7	2.8	2.4	0.9	7.0	1.4	2.9	0.9	2.4	0.9	8.5	X
Flash Evaporator					0.2	1.0	2.8	2.4	0.8	7.2	1.4	2.8	0.7	2.4	0.9	8.2	

(1) Operability
(2) Cost

EXPENDABLE PHASE CHANGE

Two different expendables were evaluated. These were limited to fluids having other life support system functions to reduce the need for additional fluid storage systems.

- Water
- Cryogenic Oxygen

The cryogenic oxygen also supplies the metabolic oxygen and suit leakage, accounting for only one percent of the total oxygen. The cryogenic oxygen heat sink sized to handle cooling loads is ten times heavier than a water heat sink and is thus non-competitive.

Having chosen water as the optimum expendable, three methods of utilizing it are available:

- Sublimator
- Water Boiler
- Flash Evaporator

The water boiler was rejected because of wick filling problems and higher weights and volumes. The flash evaporator concept was rejected because it required more volume, was heavier and was more costly than the sublimator concept. The sublimator was selected to be used with water as an expendable. The accompanying table shows the evaluation of the expendable heat sinks. They all meet the go/no-go criteria. They are all equal in vehicle weight and volume. The sublimator has the smallest pack volume, the lowest cost, and is equal in flexibility to the flash evaporator.

The water boiler was down-rated in flexibility, as a new boiler with integral water tank and wicks must be designed for longer missions. For the flash evaporator and sublimator, duration is extended merely by enlarging water tanks. The sublimator has the best rating based on both the primary criteria and the secondary criteria. It is a clear winner over the other concepts.

During the period of the space program that water is available as a fuel cell byproduct, sublimated water is clearly the recommended approach. However, when fuel cell water is no longer available, it would be necessary to resupply approximately 5,000 lbs of water, in tanks, every 90 days to support 4 EVA crewmen. This requirement drives the search for a non-expendable approach to thermal control.

THERMAL STORAGE PHASE CHANGE

Thermal storage is a regenerable thermal control concept that uses the heat of phase change and the heat capacitance of a material to provide thermal control. An example of a thermal storage material is ice. The heat of fusion of ice is 143.4 Btu/lb. A schematic of a typical thermal storage concept is as shown. Water pumped through the thermal storage device is cooled to 40°F, and then flows to a three-fluid heat exchanger where it cools the LCG loop and the gas loop. The heated water is returned to the thermal storage device for recooling.

A summary of the properties of thermal storage materials is shown in the accompanying table. For melting temperatures above 45°F, a heat pump is required, as the temperatures are too high to cool the gas stream and the liquid cooling loop down to the required levels.

In order to evaluate heat pumps an overall compressor/motor efficiency of 20% was assumed. The accompanying graphs shows the adiabatic compressor power vs. sink temperature (condensing temperature) with a 50°F evaporator and an evaporative heat load of 1814 Btu/Hr, using Freon 11 as the refrigerant. The graphs also show the total heat that must be rejected by the heat sink, namely, the sum of the evaporator heat load and the compressor power. The graph is based on the average metabolic heat load of 1000 Btu/Hr for 8 hours and a hot environment, assuming a 5°F difference between sink temperature and condensing temperature. It can be seen that a heat pump raises the total heat to be rejected significantly.

The accompanying figure shows the total heat load, the power penalty, the heat sink material weight and the heat sink material volume. A typical system schematic of a thermal sink with a heat pump is also shown. It is assumed that "zero gravity" evaporators and condensors can be designed.

An evaluation of the subsystem concepts using the evaluation criteria is shown in the accompanying evaluation. The results include the following considerations:

- Recent testing of the KHF_2 salt solution has shown that the heat of hydration depends on the rate of freezing of the solution. With the expected rates of freezing the heat of hydration is low and the salt solution is equivalent to the ice system.

- The PH_4Cl subsystem is highly toxic and must be stored at high pressure (75 atm). It was eliminated due to its safety considerations. Availability of PH_4Cl is also doubtful, but this subsystem was not followed further as the material does not meet the safety considerations.

Based on the Primary Criteria of vehicle weight, EVA volume, reliability, operability, and flexibility, ice is the best thermal storage material. A subsystem using ice has only one moving part, a pump, is not affected by the environment, does not require a heat pump, and has the smallest volume and lowest vehicle weight. The main disadvantages are that a cold (30°F) source of cooling fluid is required in the vehicle for refreezing the thermal storage material between EVA sorties, and the subsystem is much larger than an expendable system. Present estimates of size and weight for an 8-hour, regenerable, phase-change heat sink, based upon ice, are on the order of 3 ft^3 and 200 lbs. These values are excessive, and drive the search for a smaller and/or lighter heat rejection approach.

THERMAL STORAGE EVALUATION

Subsystem	Go/No-Go				Primary						Secondary					
	Performance	Safety	Availability	Acceptability	Vehicle Weight	Pack Volume	Reliability	Cost	Flexibility	Summary	Vehicle Volume	Pack Weight	Interface Compt.	Maintainability	Operability	Summary
KH F_2	N	X	X	X	–	–	–	–	–	–	–	–	–	–	–	–
ICE[1]	X	X	X	X	10	10	8	7.7	9	34.7	10	10	9	10	9	38
$C_{14}H_{30}$	X	X	X	X	–	1	8	7.7	9	25.7	–	8.5	9	10	9	36.5
$C_{16}H_{34}$	X	X	X	X	–	0	5	6	9	20	–	6.4	8	8	8	30.4
$C_{17}H_{36}$	X	X	X	X	–	0	5	6	9	20	–	5.0	8	8	8	29
PH_4 CL	X	N	–	X	–	–	–	–	–	–	–	–	–	–	–	–
$LiHO_3$ 0.3 H_2O	X	X	X	X	–	9.5	5	6	9	29.5	–	6.3	8	8	8	30.3
NO_2 HPO_4 0.12 H_2O	X	X	X	X	–	6	5	6	9	26	–	4.8	8	8	8	28.8
$C_{18}H_{38}$	X	X	X	X	–	0	5	6	9	20	–	0	8	8	8	24
EDO					0.3	0.3	0.15	0.1	0.15		0.3	0.2	0.1	0.2	0.2	
ICE					3.0	3.0	1.2	0.8	1.4	9.4	3.0	2.0	0.9	2.0	1.8	9.7
FFM					0.3	0.2	0.1	0.2	0.2		0.3	0.2	0.1	0.2	0.2	
ICE					3.0	2.0	0.8	1.5	1.8	9.1	3.0	2.0	0.9	2.0	1.8	9.7
SS					0.3	0.1	0.2	0.2	0.2		0.2	0.2	0.1	0.3	0.2	
ICE					3.0	1.0	1.6	1.5	1.8	8.9	2.0	2.0	0.9	3.0	1.8	9.7
LSC					0.1	0.1	0.4	0.3[2]	0.1		0.2	0.3	0.1	0.3	0.1[3]	
ICE					1.0	1.0	3.2	2.7	0.9	8.8	2.0	3.0	0.9	3.0	0.8	9.7

(1) Ice is Not Excelled by Any Other PCM in all Ratings, Therefore Ice Ranks Highest with Weighing Factors.

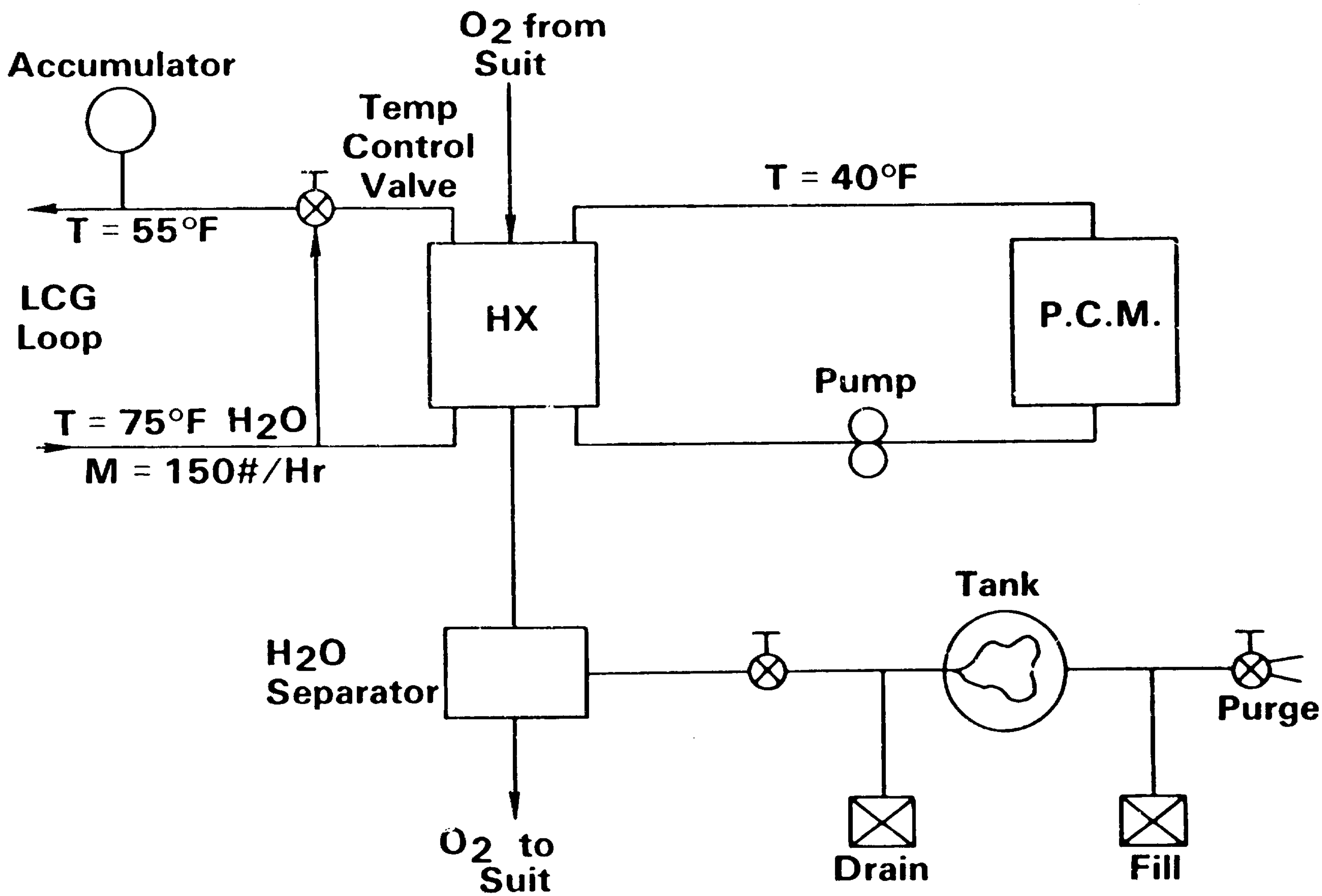
(2) Operability

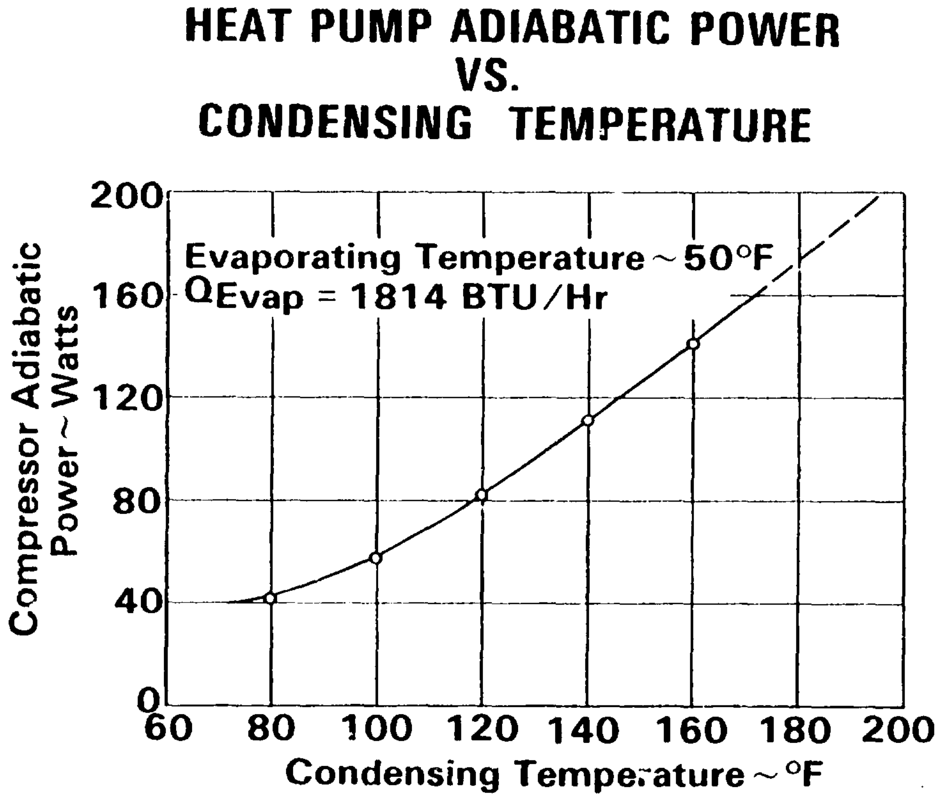
(3) Cost

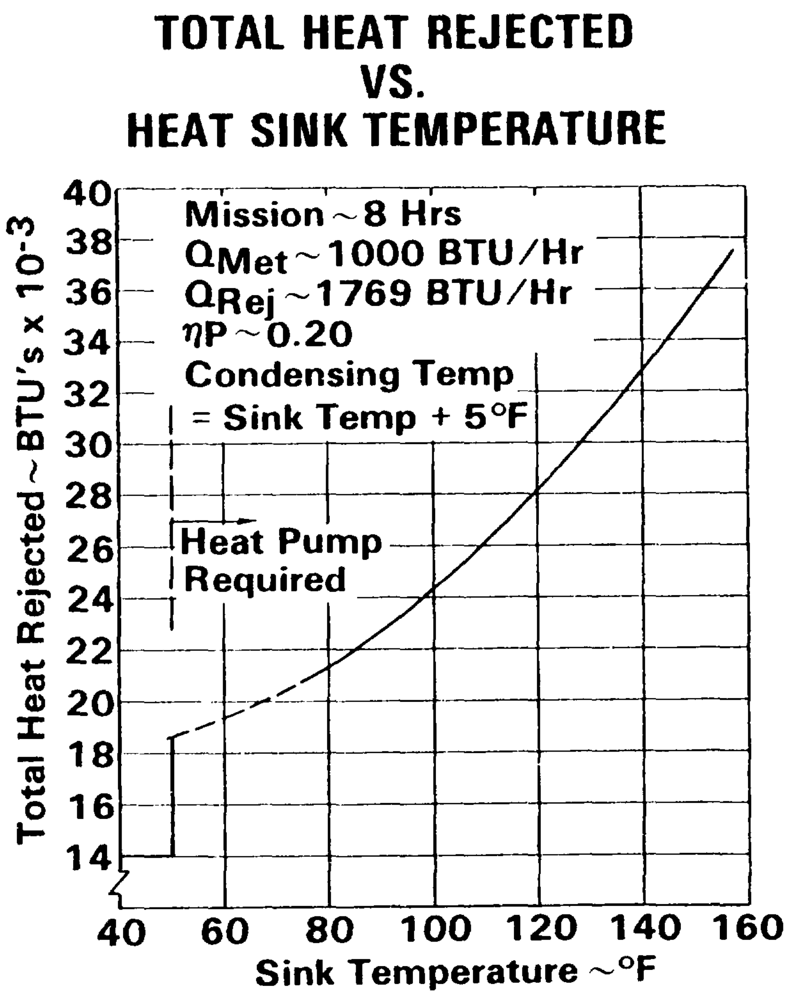
PROPERTIES OF PHASE CHANGE MATERIALS CONSIDERED AND THERMAL STORAGE FOR DESIGN MISSION

Phase Change Material	Melting Point °F	Latent Heat	Total Heat Load (BTU's)	Power Penalty (Lbs)	Material Weight (Lbs)	Density	Material Volume (In^3)
1) Potassium Bifluoride, KHF_2 (30% Sol't'n in H_2O)	10.4°F	218 BTU/#	14,152	0	65	67.4 #/Ft^3	1666
2) Water – Ice, H_2O	32	143.1	14,152	0	99	57.24	2988
3) N-Tetradecane, $C_{14}H_{30}$	41.9	98	14,152	0	144	51.5	4832
4) N-Hexadecane, $C_{16}H_{34}$	62.1	102.0	18,500	32	181	52.1	6003
5) N-Heptadecane, $C_{17}H_{36}$	71.1	92	20,300	36	221	48.6	7858
6) Phosphonium Chloride PH_4C	82	324	21,600	42	67	106.1	1091
7) Lithium Nitrate Trihydrate, $LiNO_3 \cdot 3H_2O$	85.8	128	22,100	44	173	96.8	3088
8) Sodium Hydrogen Phosphate Dodecahydrate, $Na_2HPO_4 \cdot 12\ H_2O$	97	114	23,700	53	208	94.9	3787
9) N-Octacosane, $C_{18}H_{38}$	142.9	109	33,600	108	308	48.6	10,951

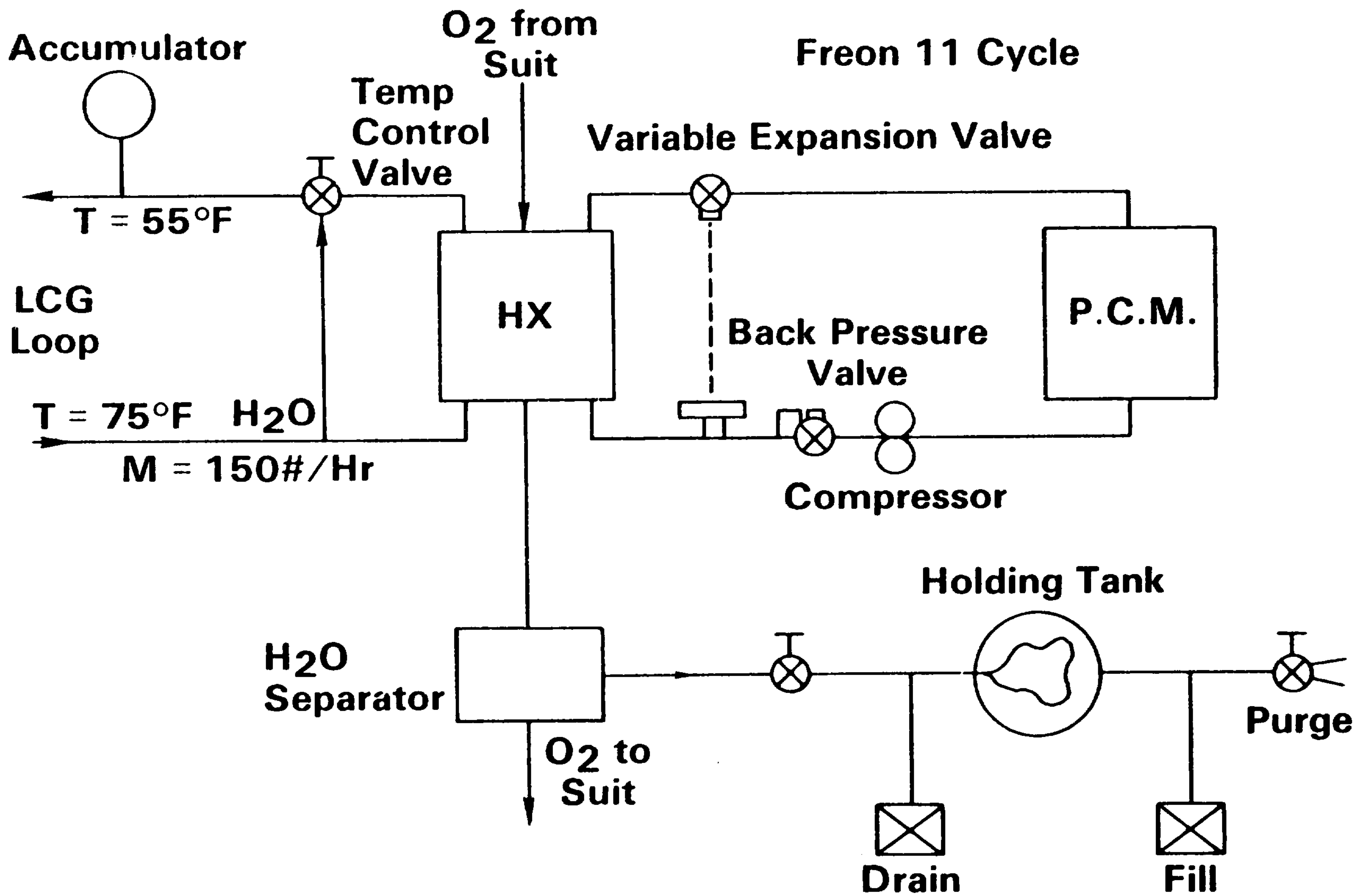
HEAT STORAGE WITH PHASE CHANGE MATERIAL




HEAT PUMP ADIABATIC POWER
VS.
CONDENSING TEMPERATURE
Evaporating Temperature ~ 50°F
QEvap = 1814 BTU/Hr
Compressor Adiabatic Power ~ Watts
0
40
80
120
160
200
60
80
100
120
140
160
180
200
Condensing Temperature ~ °F


TOTAL HEAT REJECTED
VS.
HEAT SINK TEMPERATURE
Mission ~ 8 Hrs
QMet ~ 1000 BTU/Hr
QRej ~ 1769 BTU/Hr
ηP ~ 0.20
Condensing Temp
= Sink Temp + 5°F
Heat Pump
Required
Total Heat Rejected ~ BTU's x 10-3
14
16
18
20
22
24
26
28
30
32
34
36
38
40
40
60
80
100
120
140
160
Sink Temperature ~ °F

TYPICAL HEAT STORAGE SYSTEM WITH HEAT PUMP



RADIATORS

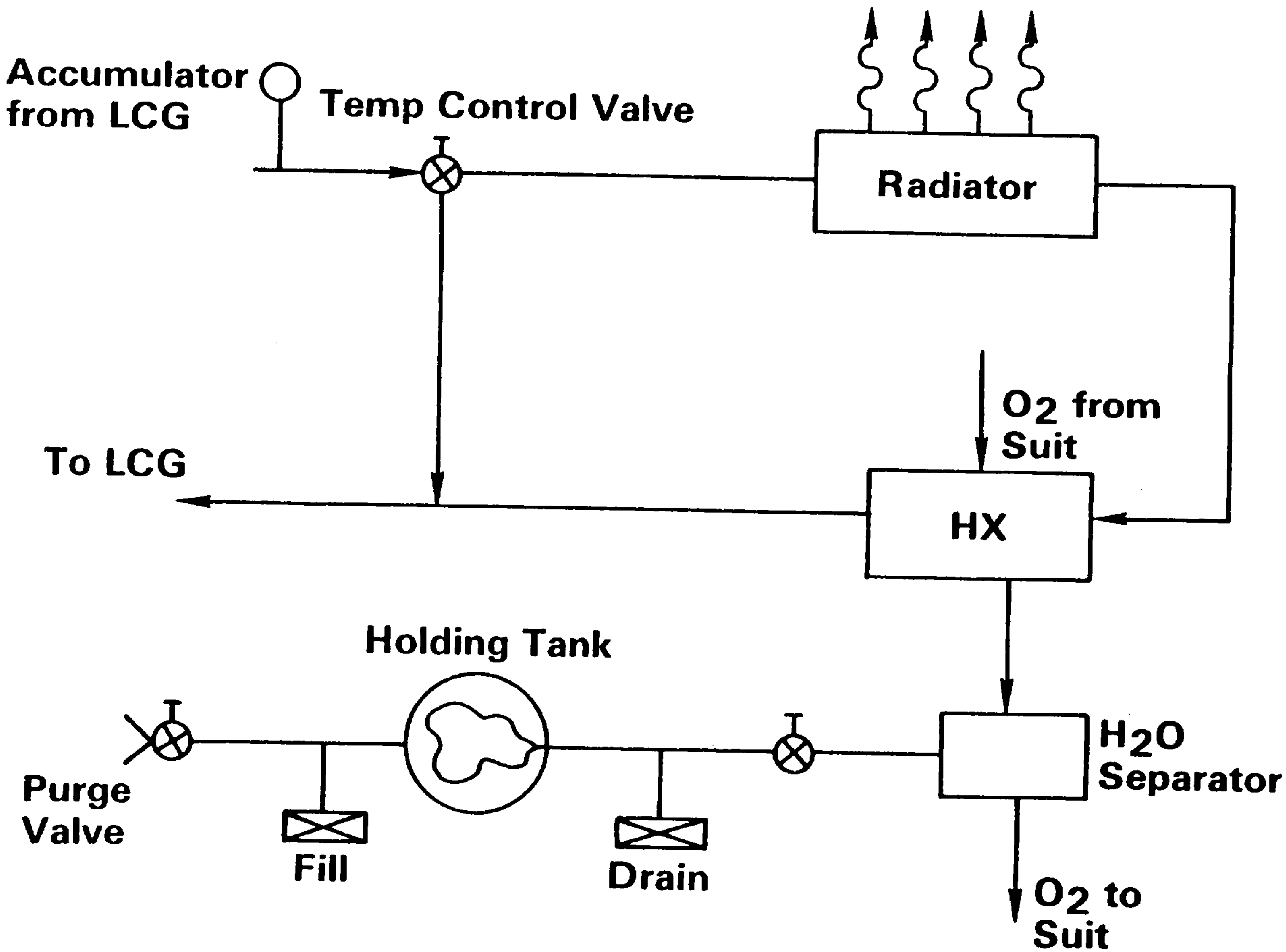
Direct radiative cooling is a non-expendable concept that dissipates heat to deep space. A schematic of a radiator cooling system is shown in the accompanying figure. For this system the LCG loop is cooled by the radiator. The cool LCG water then flows to the heat exchanger where the gas loop heat is dissipated. An automatic temperature control valve varies flow to the radiator to control temperature.

Since the radiator is sized for the nominal thermal load, prevention of overcooling of the crewman and/or freezing of the LCG loop at low load conditions is required. Sizing is affected by the solar heat input, the structure temperature and view factor, the ground view factor, and the radiator values of emission and absorbtivity. Assuming no heat input from the environment and an emissivity of 1.0 (maximum), 15 square feet of radiator surface would be required to reject the peak heat load at 50°F. Examination of a potential LSS package shows that only about 8 square feet of surface area could be available. Examination of the current Shuttle suit shows that very little additional surface area could be used for radiators, as electrical equipment, moving joints, connectors, seals, and equipment that must be visually monitored or manually controlled take up the majority of the suit exterior surface, a situation expected to exist with the ECWS too.

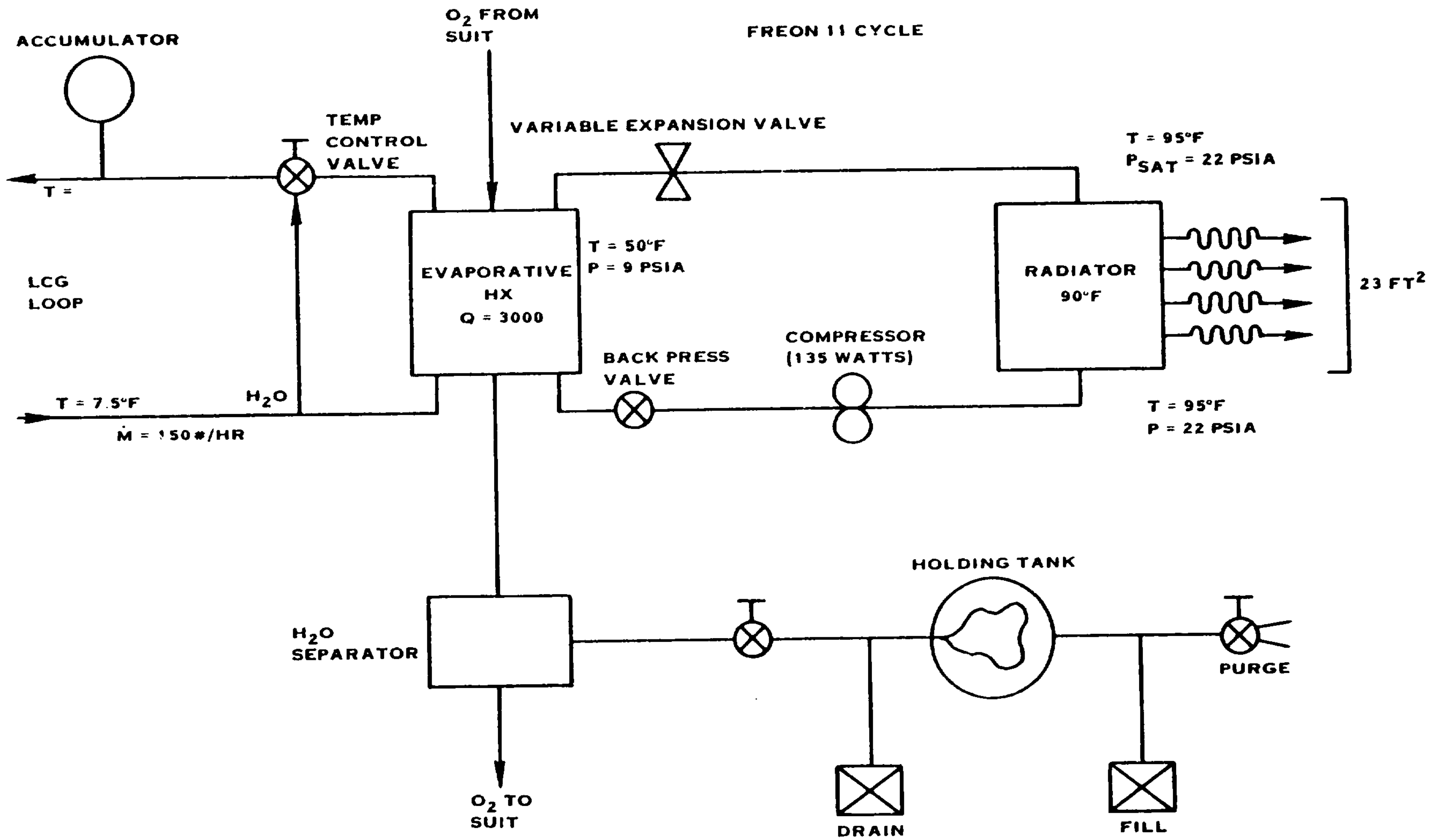
As the surface area required for radiation is proportional to the 4th power of the "absolute temperature", a heat pump could be used to raise the radiating temperature. The accompanying figure shows a schematic of a heat pump system to raise the radiating temperature from 50°F to 90°F. This would reduce the radiator area requirement from 15 ft^2 to 13 ft^2, which is not a significant benefit. The reason that the area savings is so small is because the heat of the compressor must also be rejected by the radiator, thus increasing the heat rejection rate.

The largest unknown in the radiator subsystem is the heat picked up by the radiator from the structure on which the crewman is working. As the structures can be hot (up to +200°F) and will radiate in the infrared region, the radiator may pick up heat instead of rejecting it. The uncertainty of structural heat pick up prevents radiators from being considered as the sole heat rejection means for ECWS. This shortcoming drives the search for a hybrid heat rekection subsystem, or for some other concept.

SCHEMATIC OF DIRECT RADIATIVE COOLING CONCEPT



90°F RADIATIVE COOLING WITH HEAT PUMP



HYBRID HEAT SINK CONCEPT

To circumvent the difficulties associated with sole reliance upon the phase change material (PCM), sublimator or radiator concepts, two hybrid concepts were generated, namely:

- Sublimator/PCM

- Radiator/PCM

These were evaluated against the sole use of PCM and against the sole use of the sublimator. The results of the trade are illuminating, namely:

- When adequate vehicle water supply is available, the sublimator expendable mode remains the clear winner through all mission and vehicle trends.

- When no vehicle water is available, the PCM/radiator hybrid becomes the clear winner through all mission and vehicle trends.

The hybrid heat sink follows the trends of reduced water availability, and increased EVA volume allowed. The breakpoint, requiring use of the radiator, comes when expendable water becomes unavailable.

HYBRID HEAT SINK EVALUATION

Subsystem	Go/No-Go				Primary						Secondary					
	Performance	Safety	Availability	Acceptability	Vehicle Weight	Pack Volume	Reliability	Cost	Flexibility	Summary	Vehicle Volume	Pack Weight	Interface Compt.	Maintainability	Operability	Summary
Thermal Storage	G	G	G	G	9.8	0	8	7.7	9	34.5	8.4	1.1	9	10	9	37.5
Expendables	G	G	G	G	2.1	8.2	7	8.8	8	27.1	7.2	8.3	8	1.8	8	41.5
Radiators	X	G	G	X												
Sub/Ice					5.4	2.5	8.8	6.8	10	33.5	7.4	3.7	7	9	7	34.1
Ice/Rad					9.8	3.1	8.0	6.2	10	37.1	8.8	4.3	8	9	8	38.1
EDO					0.3	0.8	0.15	0.1	0.15		0.3	0.2	0.1	0.2	0.2	
Ice	G	G	G	G	2.9	0	1.2	0.8	1.4	7.7	2.5	0.2	0.9	2.0	1.8	7.4
Sub	G	G	G	G	3.0[1]	2.5	1.1	1.0	1.4	9.5	3.0[1]	1.7	0.8	2.0	1.6	9.1
Sub/Ice	G	G	G	G	1.6	0.8	1.3	0.7	1.5	5.9	2.2	0.7	0.7	1.8	1.4	6.8
Ice/Rad[4]	G	G	G	G	2.9	0.9	1.2	0.6	1.5	7.1	2.6	0.9	0.8	1.8	1.6	7.7
FFM					0.3	0.2	0.1	0.2	0.2		0.3	0.2	0.1	0.2	0.2	
Ice	G	G	G	G	2.9	0	0.8	1.5	1.8	7.0	2.5	0.2	0.9	2.0	1.8	7.4
Sub	G	G	G	G	0.7	2.5	0.7	1.8	1.6	7.3	2.2	1.7	0.8	2.0	1.6	8.3
Sub/Ice	G	G	G	G	1.6	0.8	0.9	1.4	2.0	6.7	2.2	0.7	0.7	1.8	1.4	6.8
Ice/Rad[4]	G	G	G	G	2.9	0.9	0.8	1.2	2.0	7.8	2.6	0.9	0.8	1.8	1.6	7.7
SS					0.3	0.1	0.2	0.2	0.2		0.2	0.2	0.1	0.3	0.2	
Ice	G	G	G	G	2.9	0	1.6	1.5	1.8	7.8	1.7	0.2	0.9	3.0	1.8	7.6
Sub	G	G	G	G	0.7	0.8	1.4	1.8	1.6	6.3	1.4	1.7	0.8	3.0	1.6	8.5
Sub/Ice	G	G	G	G	1.6	0.3	1.8	1.4	2.0	7.1	1.5	0.7	0.7	2.7	1.4	7.0
Ice/Rad[4]	G	G	G	G	2.9	0.3	1.6	1.2	2.0	8.0	1.8	0.9	0.8	2.7	1.6	7.8
LSC					0.1	0.1	0.4	0.3[2]	0.1		0.2	0.3	0.1	0.3	0.1[3]	
ice	G	G	G	G	1.0	0	3.2	2.7	0.9	7.8	1.7	0.3	0.9	3.0	0.8	6.7
Sub	G	G	G	G	0.2	0.8	2.8	2.6	0.8	7.2	1.4	2.5	0.8	3.0	1.0	8.7
Sub/Ice	G	G	G	G	0.5	0.3	3.5	2.1	1.0	7.4	1.5	1.1	0.7	2.7	0.7	6.7
Ice /Rad	G	G	G	G	1.0	0.3	3.2	2.4	1.0	7.9	1.8	1.3	0.8	2.7	0.6	7.2

(4) Best Choice if Vehicle H_2O is Not Available

(3) Cost

(2) Operability

(1) H_2O is Relatively Unlimited

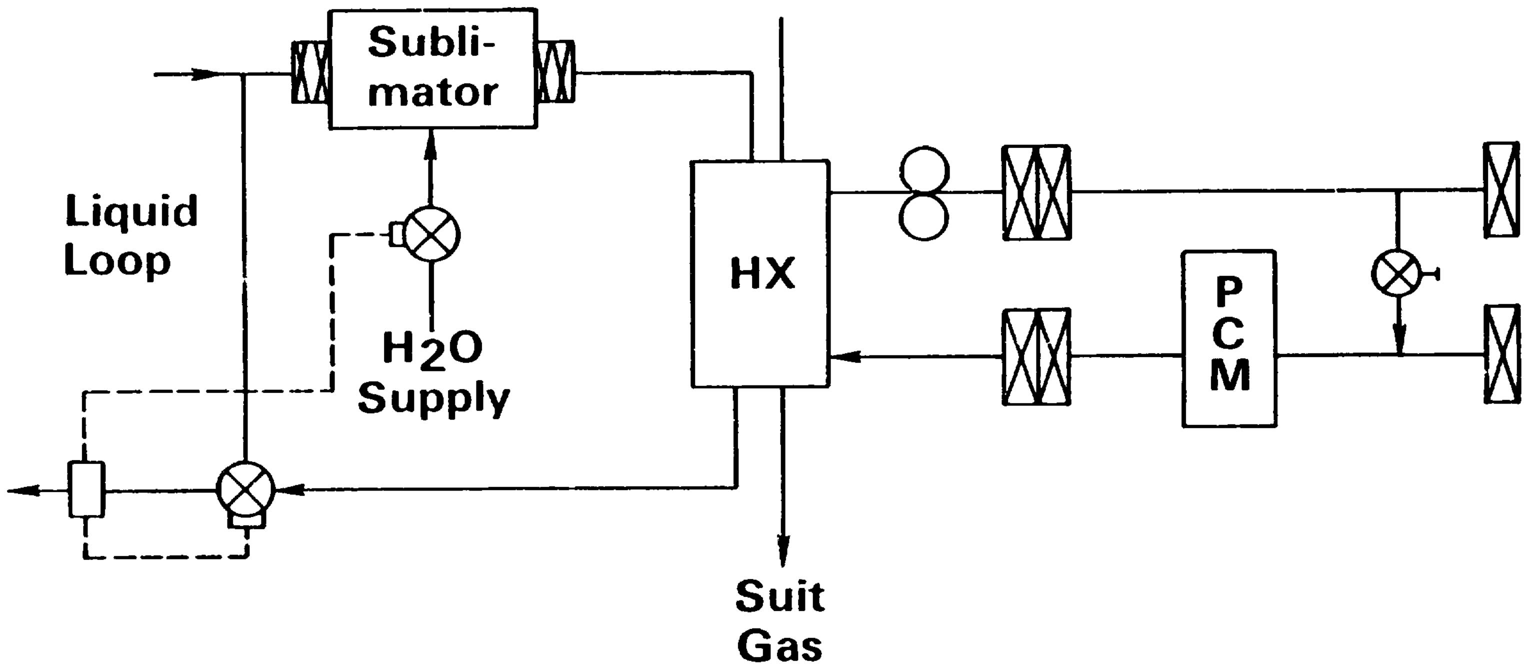
HYBRID HEAT SINK CONCEPT (Continued)

The hybrid heat sink trades drove the concept of heat hybrid heat sink approach to one of convertability to meet various levels of water availability. The key to the concept is using a building block approach to permit tailoring the EVA thermal control to the water availability in each mission.

Features of the concept are:

- Make the sublimator and its water supply separable from the LSS. Put the sublimator in the LSS liquid loop, and include a heat exchanger that can cool suit gas either via the sublimator or by ice acting as a phase change material. The sublimator and the water supply are installed or removed on earth prior to flight. When adequate water is available, the sublimator can be used as the sole heat rejection mode.

HYBRID HEAT SINK CONCEPT – SUBLIMATOR IN LOOP



HYBRID HEAT SINK CONCEPT (Continued)

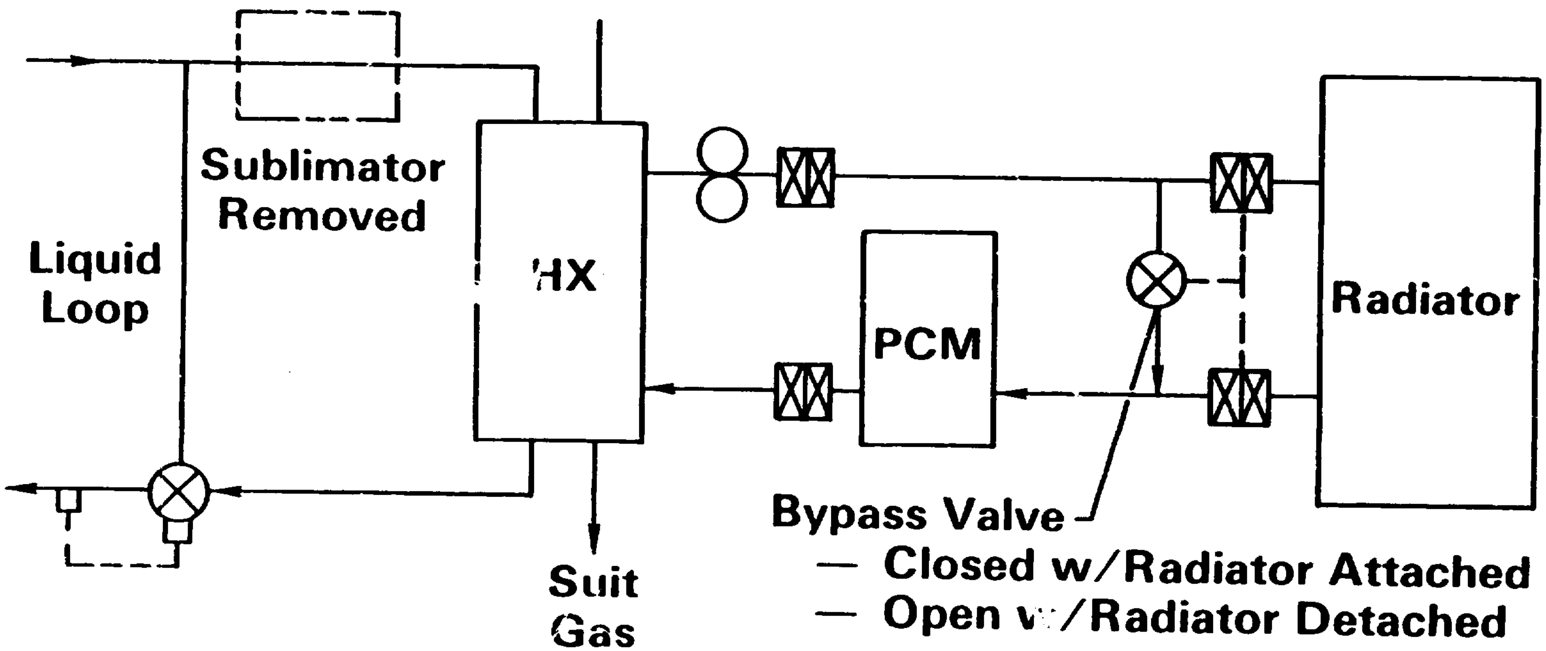
- Provide a 4-hour, regenerable, ice phase change material heat sink building block. In use the ice melts and is used to cool the crewman, cooling both the LSS suit gas and the liquid loops. As the melting occurs at constant temperature, a constant temperature heat sink is circulated. The only moving part is the pump, which circulates liquid from the PCM to the heat exchanger. The PCM is regenerable in flight. It is separate from the LSS liquid loop to permit its being refrozen without breaking the LSS liquid lines in flight, and permits the sublimator to be used for cooling without depending on the PCM pump. When used, as shown, in con junction with the sublimator, the sublimator water usage is reduced to 4 hours. In this configuration the sublimator is available to supplement the PCM, being activated only when the bypass valve, set to maintain heat exchanger outlet temperature of $47 \pm 3°F$, is wide open and calling for more cooling.

MODE	WATER AVAILABILITY	EXPENDABLE/REGENERABLE USE
Sublimator	Adequate	H_2O - 8 Hr.
Sublimator/PCM	Marginal	H_2O - 4 Hr., Ice - 4 Hr.

- Adding the radiator building block eliminates the need for using any expendable vehicle water. For such missions the sublimator and its water supply would be removed on earth, prior to flight. The 15 ft^2 radiator, would be added to the LSS during EVA. It can be left at the work site, permitting the crewman to use the PCM during transit between the airlock and worksite. During periods of low solar influx the radiator will tend to refreeze the PCM. It too, can be added and removed without breaking the LSS liquid loop.

MODE	WATER AVAILABILITY	EXPENDABLE/REGENERABLE USE
Radiator/PCM	None	Radiator - 4 Hr., Ice - 4 Hr.

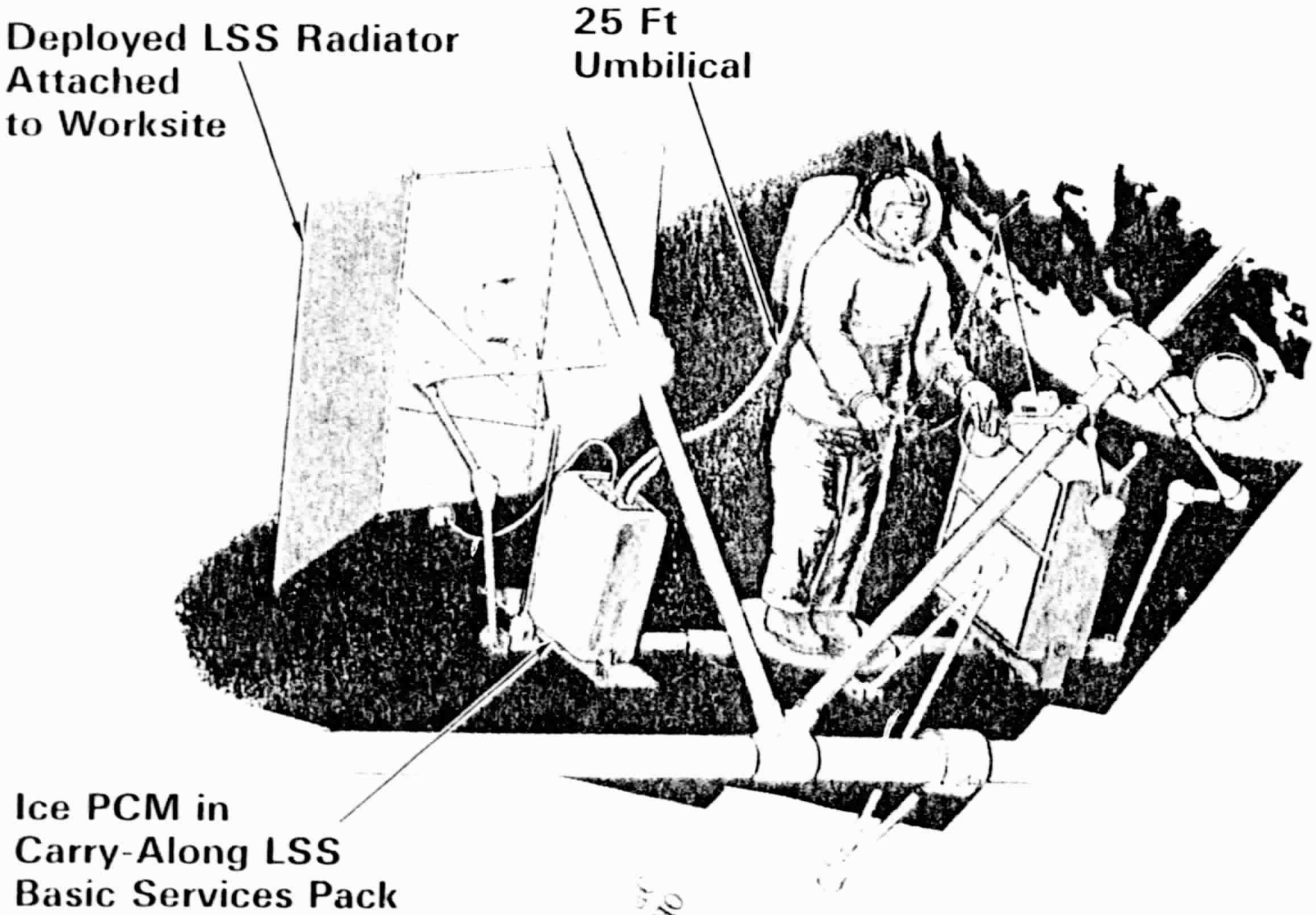
HYBRID HEAT SINK CONCEPT — RADIATOR ADDED



GENERAL ARRANGEMENT OF THE HYBRID HEAT SINK

The accompanying illustration shows the radiator/PCM version of the hybrid heat sink concept, deployed at the worksite. The radiator remains at the worksite, while the ice PCM is carried along to and from the worksite, and set down at the worksite. During transit to and from the worksite the PCM, in its carry-along package, may be fastened to the pack remaining on the crewman's back. In this concept the radiator consists of three panels hinged together. Each panel is approximately 1.7 ft. x 3 ft. providing a deployed area of approximately 15 ft^2. When folded, the radiator could be stored inside the vehicle, as it will pass through 1 m dia. airlock hatch.

GENERAL ARRANGEMENT OF NON-VENTING HEAT SINK



ALTERNATIVE RADIATOR CONCEPTS

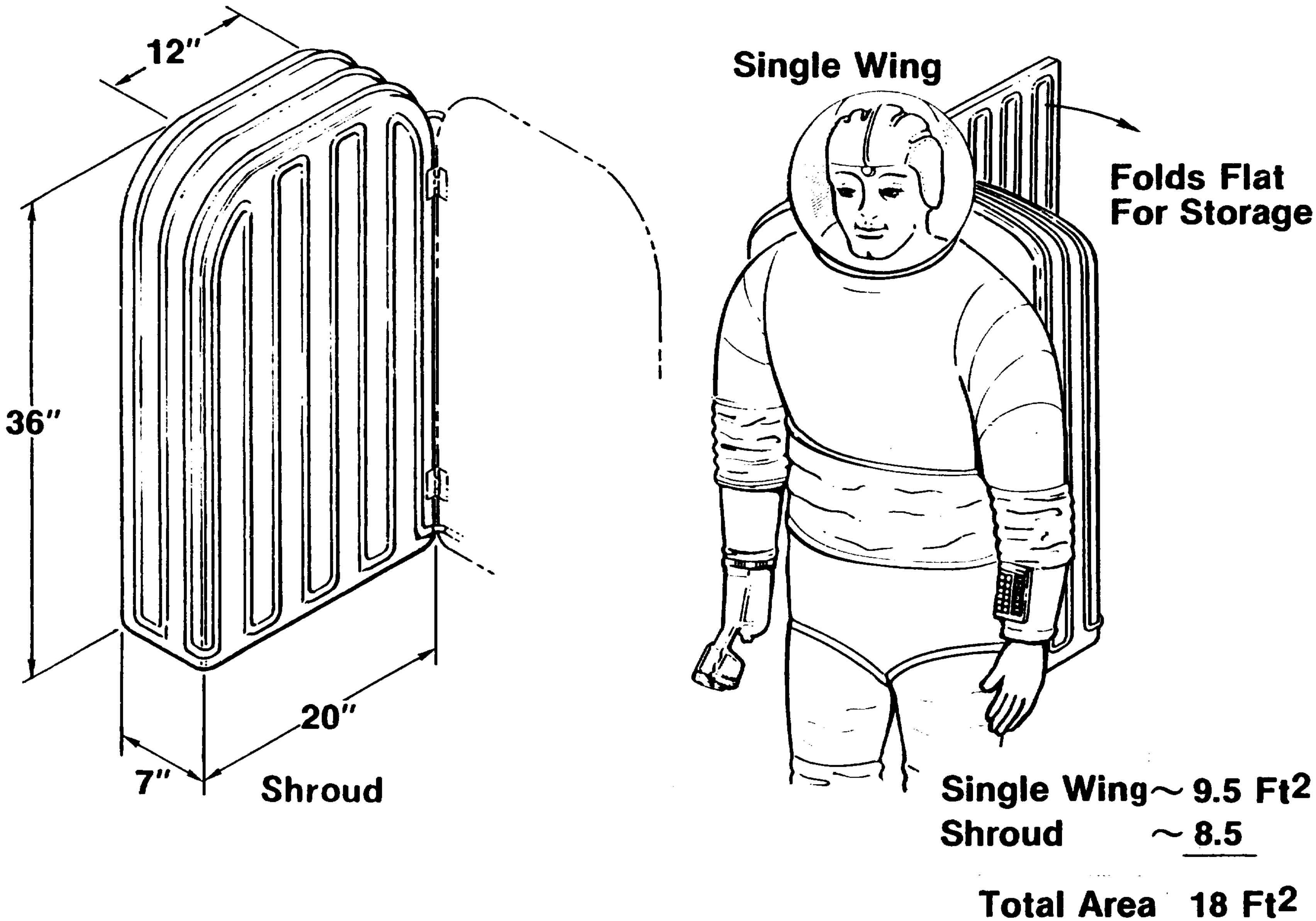
The folding radiator concept is but one potential radiator concept. Several other concepts are also promising, and are shown in the accompanying figures.

- Shroud and Wing Radiator - The shroud and wing radiator uses one wing panel in combination with the LSS package surface area as a radiator. During most EVA's the crewman will face the structure, and thus his back will face open space. The shroud has an area of approximately 8 ft^2, and one wing panel has approximately 7.6 ft^2, for a total radiator surface of 15.6 ft^2.

  The shroud and wing concept can be used several ways, namely:

  - Reduce the size of a workstand radiator by approximately one-half
  - Top off a PCM pack to reduce its size
  - Shield the crewman from radiation, and thus reduce total radiation shielding requirements
  - Shield the crewman from solar thermal radiation, and thus reduce peak solar heat input into the ECWS. This in turn would reduce the amount of PCM required.

SHROUD AND WING RADIATOR CONCEPT



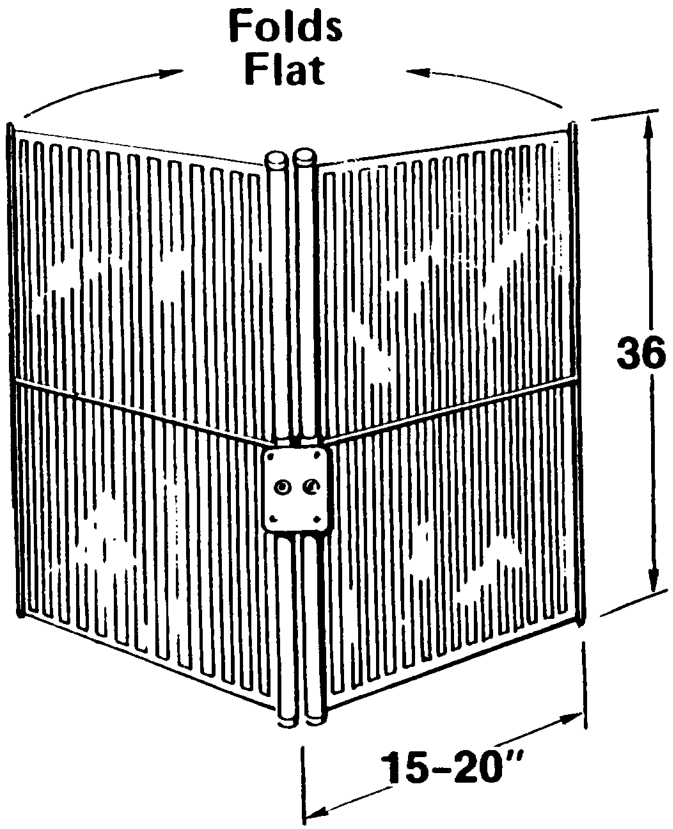
ALTERNATIVE RADIATOR CONCEPTS (Continued)

- Wing Radiator - The wing radiator uses two radiator panels deployed as "wings" from the crewman's back. This concept offers the same advantages as the shroud concept, and adds several additional features; namely:
  - These panels would be steerable, and would thus be oriented away from IR sources, within limits.
  - They could be sized to handle the entire heat flux, thus eliminating the requirement for the radiator on the workstand.

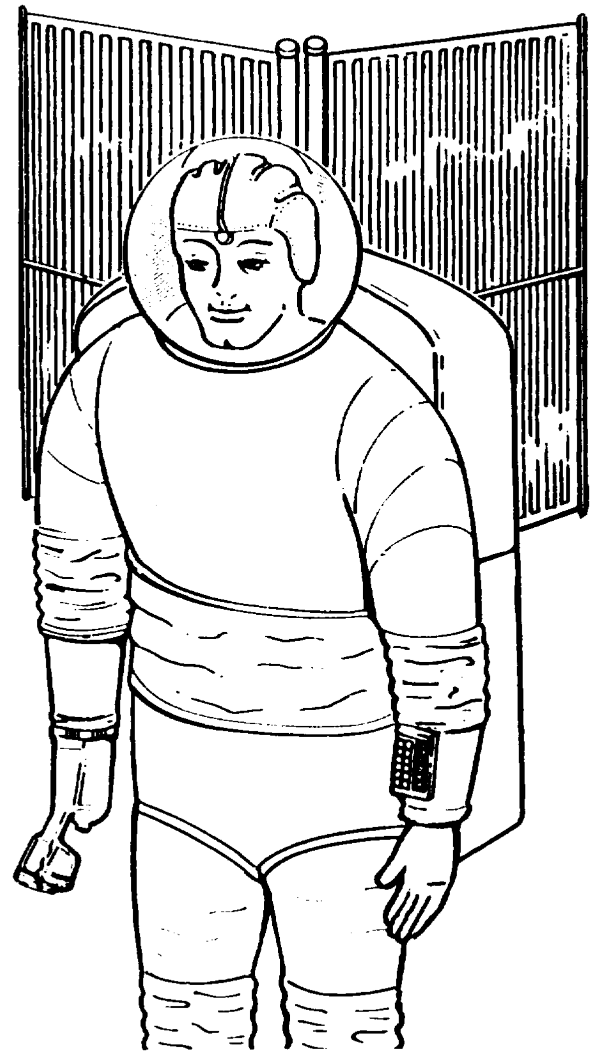
All radiator concepts require new technology development. Specific issues to be evaluated and developed are:

- Provision for automative shutdown in the presence of IR influx.
- Best radiator shape to support needs of EVA crewman.
- Ability to connect and disconnect radiator and LSS in vacuum.
- Improve surfaces to maximize emittance (e) and to minimize absorbtion (α).
- Evaluate structural concepts for deployment, stowage and mounting.
- Demonstrate ability of coatings to withstand prolonged exposure to space, environment.

"WING" RADIATOR CONCEPT



15-20 FT^2 Surface
2 Sided Radiator



CONDENSATE MANAGEMENT

Condensate management concepts were presented and evaluated in the Background Experience Report (BER), HSER 7200, December 1977. The conclusions from the BER and the ECWS sensitivity analysis are:

- Slurper/Rotary Separator, currently being developed for Shuttle EMU, is the best choice using existing technology.

- Membrane Separator offers new technology opportunity to eliminate moving parts.

Previous studies have shown that the best method of humidity control is to condense the water from the gas stream and then to separate it. That conclusion was reviewed and reconfirmed for this study. Hence, desiccants were not considered in this study.

The best primary ratings are for the rotary separator concepts, with the slurper/rotary separator system being chosen for the EVA LSS. In evaluating to the primary criteria, none of the concepts has a significant effect on the vehicle weight or EVA LSS volume. The volume for the wick type separators is larger than for other concepts due to storage of water in a wick plus the additional means of expelling the water. The wick systems were judged to be lower in reliability, as there are more ways that these systems can fail such that crew safety would be affected.

The wick systems were less expensive to build, develop and qualify. The wick systems were higher in maintenance time (drying) and have more interfaces. The rotary separator system had the highest power and was also heavier as it handles the entire gas flow rate.

The flexibility of the wick systems was judged to be poorer than the other systems.

The fan separator concept, similar to the rotary separator concept, was rejected as its performance was not acceptable. The vent loop fan would have to be downstream of the condensing heat exchanger and the fan heat would raise the ventilation loop inlet temperature to too high a level. It also takes more power than the other concepts.

The slurper/rotating separator, is currently being developed for the Shuttle EMU because of its small volume, weight, and power, and on balance is still the optimum current technology selection for the ECWS.

CONDENSATE MANAGEMENT EVALUATION

Subsystem	Go/No-Go				Primary						Secondary					
	Performance	Safety	Availability	Acceptability	Vehicle Weight	Pack Volume	Reliability	Cost	Flexibility	Summary	Vehicle Volume	Pack Weight	Interface Compt.	Maintainability	Operability	Summary
Rotary Sep.	G	G	G	G	–	10	8	8.1	9	35.1	–	10	7	8	9.5	34.5
Elbow Wick Sep.	G	G	G	G	–	10	7	8.9	8	33.9	–	10	9	7	9	35
Elbow Scupper/Rotary Sep.	G	G	G	G	–	10	8	8.1	9	35.1	–	10	7	8	9.5	34.5
Scupper/Wick Storage	G	G	G	G	–	10	7	8.9	8	33.9	–	10	9	7	9	35
Slurper/Rotary Sep.	G	G	G	G	–	10	8	8.1	9	35.1	–	10	7	8	9.5	34.5
Slurper/Wick Sep-Storage	G	G	G	G	–	10	7	8.9	8	33.9	–	10	9	7	9	35
Fan Separator	N	G	G	G	–	–	–	–	–	–	–	–	–	–	–	–
EDO					–	0.3	0.15	0.1	0.15		–	0.2	0.1	0.2	0.2	
Rotary Sep Concepts					–	3.0	1.2	0.8	1.[illegible]	6.4	–	2.0	0.7	1.6	1.9	6.2
Wick/Scupper Concepts					–	3.0	1.0	0.9	1.2	6.1	–	2.0	0.9	1.4	1.8	6.1
FFM					–	0.2	0.1	0.2	0.2		–	0.2	0.1	0.2	0.2	
Rotary Sep. Concepts					–	2.0	0.8	1.6	1.8	6.2	–	2.0	0.7	1.6	1.9	6.2
Wick/Scupper Concepts					–	2.0	0.7	1.8	1.6	6.1	–	2.0	0.9	1.4	1.8	6.1
SS					–	0.1	0.2	0.2	0.2		–	0.2	0.1	0.3	0.2	
Rotary Sep Concepts					–	1.0	1.6	1.6	1.8	6.0	–	2.0	0.7	2.4	1.9	6.0
Wick/Scupper Concepts					–	1.0	1.4	1.8	1.6	5.8	–	2.0	0.9	2.1	1.8	5.8
LSC					–	0.1	0.4	0.3 (1)	0.1		–	0.3	0.1	0.3	0.1 (2)	
Rotary Sep Concepts					–	1.0	3.2	2.4	0.9	5.5	–	3.0	0.7	2.4	1.0	6.1
Wick/Scupper Concepts					–	1.0	2.8	2.7	0.8	5.3	–	3.0	0.9	2.1	0.9	5.9

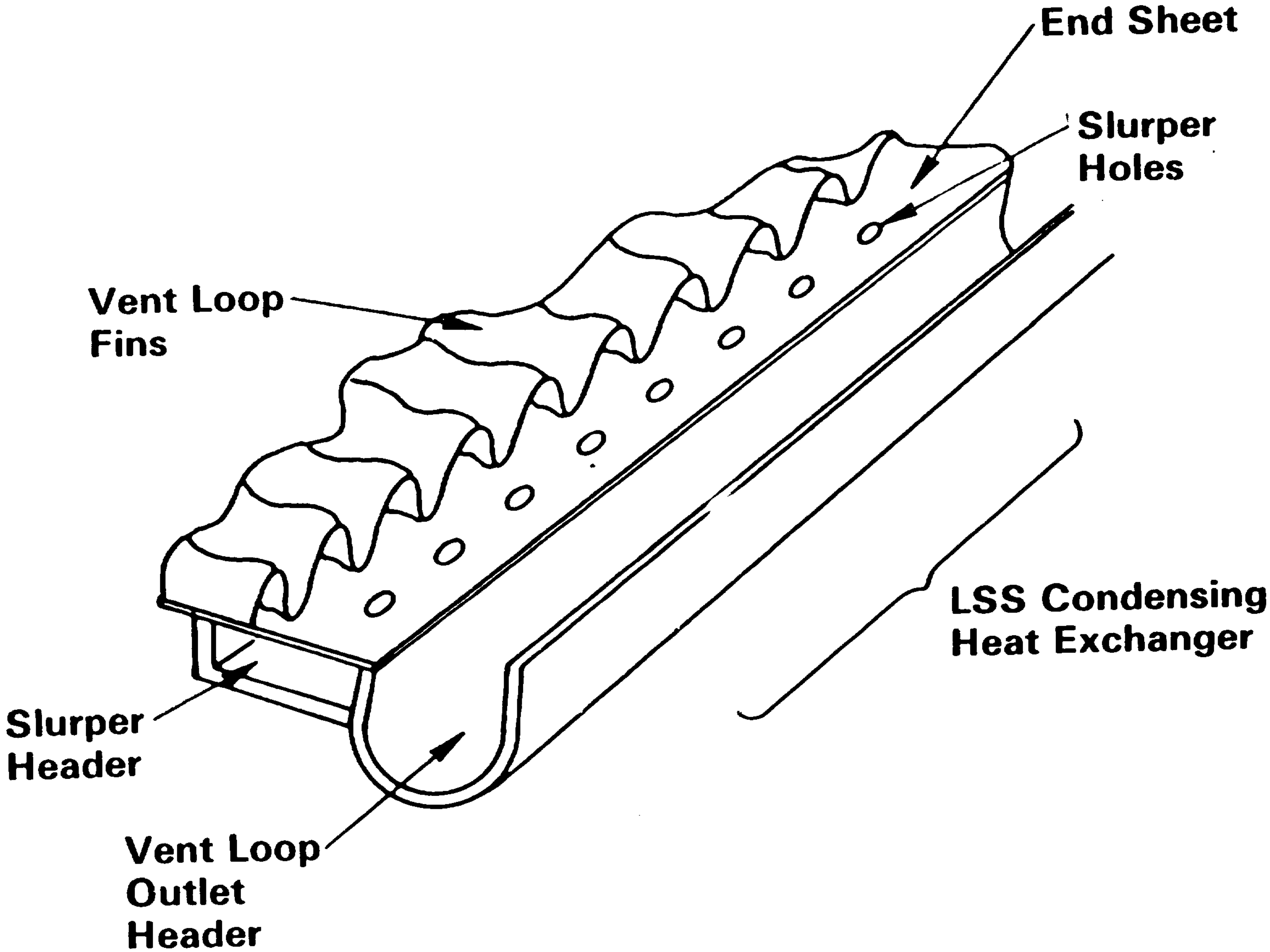
(2) Cost

(1) Operability

SLURPER

The heart of the slurper/rotary separator concept is the slurper itself. The slurper is integral with the condensing heat exchanger, and consists of an intercepter header at the end of each vent loop passage. Condensation, formed on the hydrophyllic coating within the vent passages, is drawn by the vent flow to the slurper header. Holes in the end sheets permit the condensate to be drawn into the slurper header by suction, created by the rotary separator located downstream of the slurper header, in the condensate circuit.

SLURPER

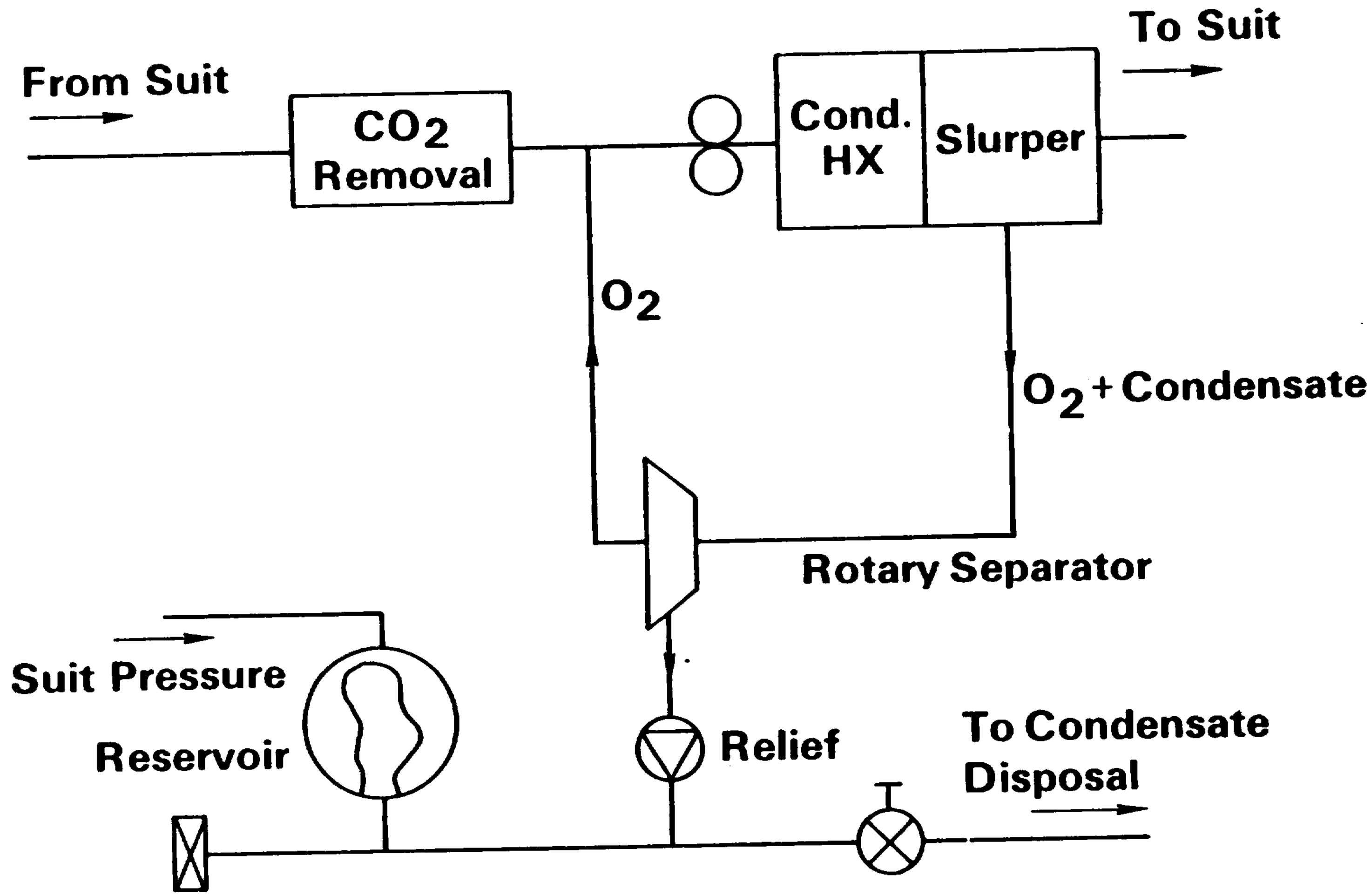


End Sheet
Slurper Holes
Vent Loop Fins
LSS Condensing Heat Exchanger
Slurper Header
Vent Loop Outlet Header

SLURPER/ROTARY SEPARATOR CONDENSATE MANAGEMENT CONTROL CONCEPT

Condensate, along with a small fraction of the vent flow gas drawn off the condensing heat exchanger slurper by the rotary separator, enters the rotary separator. The condensate and vent flow are separated in the rotary separator, the vent flow being returned to the vent loop and the condensate being pumped by the separator to a pressurized reservoir. The reservoir is emptied to the vehicle condensate disposal system after EVA.

SLURPER/ROTARY SEPARATOR CONDENSATE MANAGEMENT CONCEPT



MEMBRANE SEPARATOR CONCEPT

The membrane separator concept offers a new technology approach to eliminate moving parts from the condensate management subsystem, and to make use of components already present in the liquid cooling loop. The concept operates as follows: moisture in the suit gas is condensed in the condensing heat exchanger, and it passes immediately to the membrane water separator, where it wets the inside surfaces of the membrane bundle. Water from the liquid cooling loop passes around the outside of the membrane bundle, but owing to the lower pressure within that portion of the liquid transport loop the condensate passes through the membrane into the loop. Reduced pressure is generated within the liquid transport loop by orificing the loop just upstream of the membrane separator and by venting the backside of the liquid loop accumulator to the low side of the fan. The balance of the loop is maintained at suit pressure by the accumulator action of the LCVG tubing exposed to suit pressure.

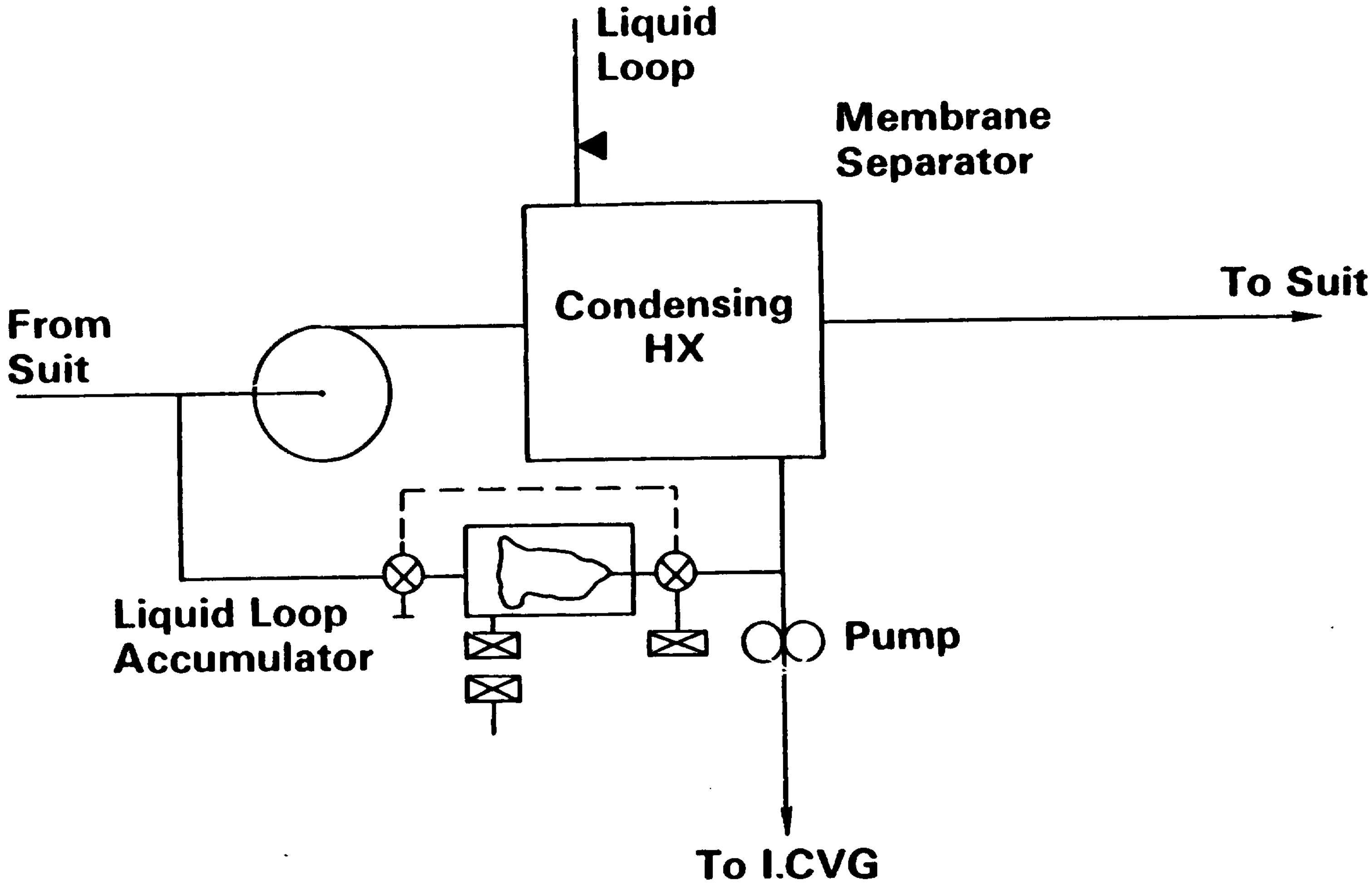
In operation the liquid loop accumulator gradually fills with transport loop fluid as condensate enters the system. After EVA, the reservoir is blown down through a disconnect connected to the vehicle waste water system by application of a slight pressure.

This subsystem integrates well with the metal oxide CO_2 removal concept, but integrates less well with the K_2CO_3 concept which requires water loss to drive off the CO_2.

Technology development is required in the following areas:

- Develop suitable membranes
- Establish system operating pressures
- Assess the potential adverse effects of contamination in the condensate and formulate means for dealing with it.

MEMBRANE SEPARATOR CONCEPT



ECWS LSS SYSTEM CONFIGURATION ISSUES

- Single vs. Multi Person LSS
- LSS Packaging Study

SINGLE VS. MULTIPERSON LSS

Single vs. multiperson LSS drives the sizing of the EVA LSS towards a one person or multiperson system, a consideration which overshadows all other sizing and packaging considerations. Therefore, this question must be addressed and answered before any further refining of packaging concepts can be attempted.

The answer to this question lies in consideration of the types of EVA tasks to be performed in support of space station operation because it drives the number and proximity of crewmembers required to perform those tasks. The illustration lists major task types within the broad categories of payload servicing and construction, and contains estimates of the projected manpower levels and proximities required to perform the EVA tasks.

The following conclusions may be drawn from the illustration.

- Most task types can be accomplished by one person. With EVA crews expected to number 2-4 people several separate tasks may be carried on in parallel.
- Alignment and checkout, which can occur over long distances, can use several people in a team effort, with various members making adjustments or using instruments.
- Positioning of large objects and assembly and alignment of beam sections can also have several crewmembers working together over moderate to long distances.

EVA TASK MANPOWER LEVELS AND PROXIMITIES

Task	No. and Proximity of Crewmen Required	
Cut/Trim	1-2	1 to 2 M
Make Holes	1	N/A
Fasten-Mechanical	1-2	Up to 30 M for Fastening a Beam on Module Section
Fasten-Weld/Fuse Bond	1	N/A
Align	1-3	Up to 250 M for SPS Test Article
Checkout	1-4	Up to 250 M for Wire-Run Trouble-Shooting
Clean/Service	1-3	2 to 3 M for Machine Service
Replenish Fluids	1	N/A
Manipulate Small Object	1	N/A
Manipulate Moderate Size Object	1	N/A
Position Large Object	1-2	Up to 20 M for Cargo Pallet

SINGLE VS. MULTIPERSON LSS CONCLUSIONS

For reasons of umbilical management, umbilicals of over 35m long (115 ft) are considered to be undesirable. The present Shuttle EMU Program does not consider the use of umbilicals or tethers over 100 feet in length. Hence, two crewmen, each using a 35m umbilical attached to a common two-man EVA LSS, could be a maximum of 70m apart, which is far short of the potential requirement to be 250m apart.

Thus a multiperson LSS would not only not meet the projected distance requirements, but would also be unnecessary for performing most EVA task types.

On the other hand, single person LSS's do not restrict proximity. Crewmen, thus equipped, could work adjacent to one another or be widely separated. Therefore, a single person LSS meets all distance and proximity requirements, and is applicable to supporting all EVA task types. A single person LSS also simplifies crew rescue operations by eliminating the necessity for having to consider the second crewman and his umbilical during an emergency and subsequent transport back to the airlock. This is a significant consideration in a high-stress situation, where the ability to take swift, decisive action is important.

As a result of the above considerations the use of the single person LSS is recommended.

LSS PACKAGING STUDY

ECWS LSS packaging concepts revolve around the rational combinations of:

- Crewman locations
- Equipment locations

Crewman Locations

During performance of EVA sortie crewmen can be located only in the following locations:

In the vehicle airlock, don-doff area or stowage areas
In a translation corridor
At a fixed worksite
On a portable worksite
Using a personal transportation system
Attached to a cherry picker or crane, 35m (115 ft) reach
Attached to a free floating tether, 30m (100 ft) length

Life Support System Locations

EVA life support equipment can be located only in the following locations:

With the crewman
In the airlock
In the workstation
On the personal transportation system
On the cherry picker or crane
As a vehicle supplied service

LSS PACKAGING STUDY (Continued)

The accompanying illustration is a matrix that identifies the rational combination of life support equipment locations and crewman locations. The matrix also identifies those combinations that require umbilicals, and typifies the umbilical lengths as being "short", 8m (25 ft) or "long", 35m (115 ft).

The long umbilical length is consistent with the maximum length considered for umbilical management reasons and is also consistent with the projected reach of the cherry picker/crane. The short umbilical length is consistent with generally accepted limitations on pressure drop and heat transfer into ventilation flow loops and is also consistent with projected requirements for "walk around" radius capability at worksites.

The illustration also identifies a number of potential combinations of crewman locations and LSS locations as being irrational. This is based on the following considerations:

- Life support equipment should not be permanently located outside the vehicle as it would require EVA time for service and maintenance.

  Since the purpose of EVA is payload service and construction, EVA to service life support equipment should be avoided. In addition externally located EVA equipment would require umbilical disconnection prior to airlock use, requiring the use of separate IVA life support means in the airlock.

- To avoid restricting the use of the cherry picker/crane or personal transportation system to one person during EVA, mounting the EVA LSS to these construction aids should be avoided.

- To avoid restricting the operational radius of the personal transportation system, use of LSS equipment located elsewhere should be avoided.

RATIONAL COMBINATIONS OF LIFE SUPPORT EQUIPMENT LOCATIONS AND CREW LOCATIONS

CREW LOCATION	LIFE SUPPORT EQUIPMENT LOCATION					
	WITH THE PERSON	IN THE WORKSTATION	ON THE PTS	ON THE CHERRY-PICKER/CRANE	IN THE AIRLOCK	VEHICLE SERVICE
VEHICLE AIRLOCK/ DON-DOFF/STOWAGE	NONE OR SHORT UMB	—	—	—	LONG OR SHORT UMB	LONG OR SHORT UMB
TRANSLATION CORRIDOR	NONE OR SHORT UMB	—	—	—	LONG UMB	LONG UMB
FIXED WORKSITE	NONE OR SHORT UMB	SHORT UMB	—	—	LONG OR SHORT UMB	LONG OR SHORT UMB
PORTABLE WORKSITE	NONE OR SHORT UMB	SHORT UMB	SHORT UMB	—	LONG UMB	LONG UMB
CHERRY-PICKER/CRANE	NONE OR SHORT UMB	—	—	SHORT UMB	LONG UMB	LONG UMB
FREE-FLOATING TETHER	NONE	LONG UMB	SHORT UMB	LONG UMB	LONG UMB	LONG UMB
PERSONNEL TRANSPORTATION SYSTEM (PTS)	NONE OR SHORT UMB	—	SHORT UMB	—	—	—

SHORT UMB = 8 M (25 FT) UMBILICAL
LONG UMB = 30 M (115 FT) UMBILICAL
— = IRRATIONAL COMBINATION OF CREW LOCATION AND LSS LOCATION

LSS PACKAGING CONCEPTS SYNTHESIS

The rational combinations of crew location and equipment location were synthesized into eight system packaging configuration concepts by considering:

- Appropriate groupings of subsystems

    Optimal packaging to facilitate maintenance

    Appropriate use of vehicle services

- Corresponding use of umbilicals

Subsystem Groupings

The LSS subsystems may be grouped as follows:

Emergency Caution & Warning Communications	Basic safety subsystem functions. These must always be carried on-the-person.
Humidity Control Ventilation CO_2 Removal	Atmosphere revitalization functions. These may be located on-the-person or connected via a 25-foot ventilation umbilical. ARS functions must always be separate from vehicle ARS functions because vehicle and EVA LSS operate at different pressures. If vehicle mounted, the ARS must be located in the airlock, because undoing a low pressure, vent loop disconnect in vacuum is prohibited by safety considerations.
O_2 Supply (high pressure) Power Cooling	Basic service functions. These may be located on-the-person or connected via a 25-foot or 115-foot O_2 makeup umbilical. These functions can be dedicated EVA equipment, or can be furnished directly as vehicle services.

LSS PACKAGING CONCEPTS SYNTHESIS (Continued)

Umbilicals

Umbilical functions may be grouped as follows:

- Tether - Communications - Cooling - Power - Makeup O_2	This group of umbilical functions comprises the O_2 makeup umbilical. It may be 25 feet or 115 feet long, and may be disconnected in a vacuum if the LSS functions are provided by other means. This umbilical would be stored on a reel to pay out just the length required.
- Tether - Communications - Cooling - Power - Vent Flow	This group of umbilical functions comprises the ventilation umbilical. It is limited to 25 feet in length, and cannot be disconnected in a vacuum. This umbilical would be stored on a reel to pay out only just the length required.

LSS PACKAGING CONCEPTS

All nine of the LSS functions can be packaged into eight LSS packaging concepts embodying the following concepts:

A single integrated self-contained, on-the-person package that may be configured two ways.

- Minimum volume
- Separable into a Time-Independent Module/and Time-Dependent Module (TIM/TDM) facilitates maintenance and expendables replenishment, but incurs a slight increase in packaging weight and volume.

The ARS functions may be packaged relative to the safety and basic functions in the following three ways:

- Integral with the safety functions as a minimum expendables, on-the-person package.
- Packaged separately and located in the airlock.
- Integrated with the basic services package below, and treated as a carry-along.

The basic services functions may also be packaged separately from the safety and ARS functions in the following two ways:

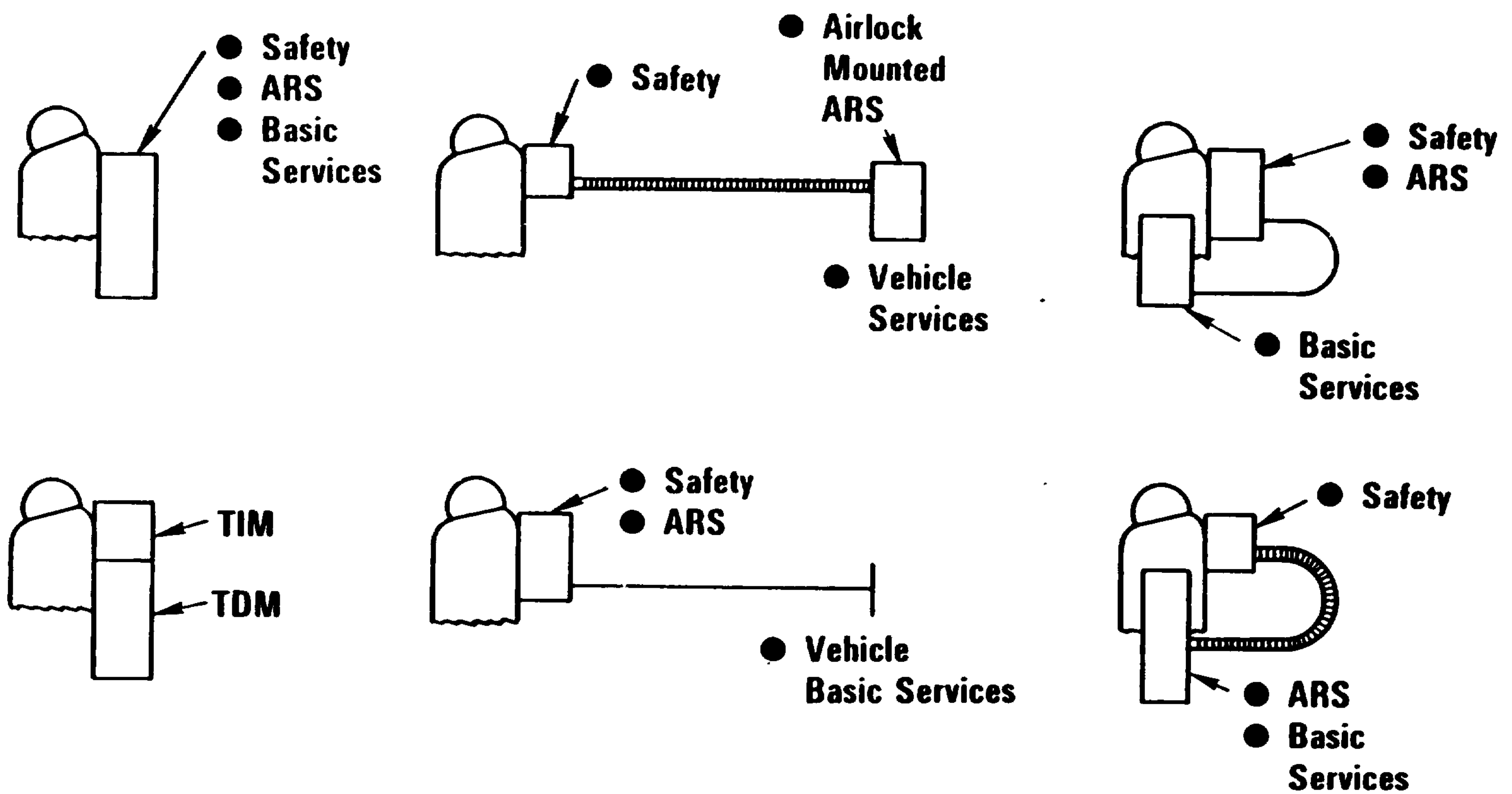
- As a carry-along
- Furnished as services by the vehicle ECLSS

The carry-along package concept has several attractive features.

- On-the-person bulk can be reduced or redistributed to facilitate EVA access to tight quarters.
- The carry-along can be set down or fastened to structure to reduce crewman fatigue in EVA operations requiring long duration upper body motion.
- The carry-along can also be attached to the person to free the hands for translating, the combining the flexibility of a self-contained EVA system with the ability to shed mass and volume when necessary.

LSS PACKAGING CONCEPTS

Integrated | Partially Vehicle Mounted/Supplied | Partially Carry-Along



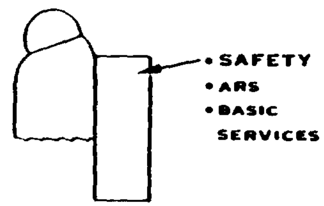
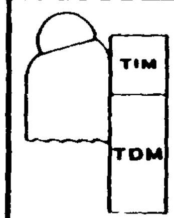
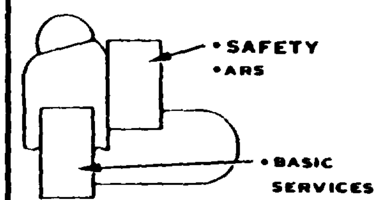
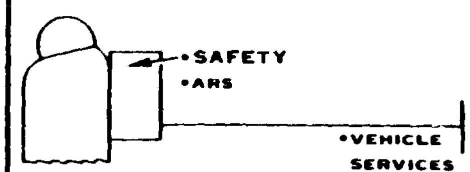
LSS SYSTEM CONFIGURATION CONCEPTS

The eight LSS packaging concepts are as follows:

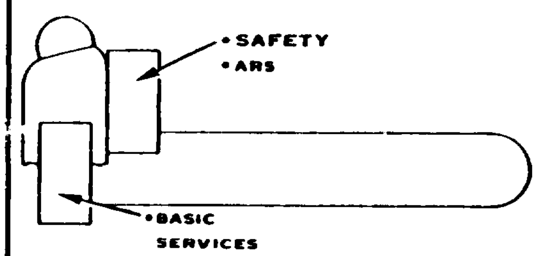
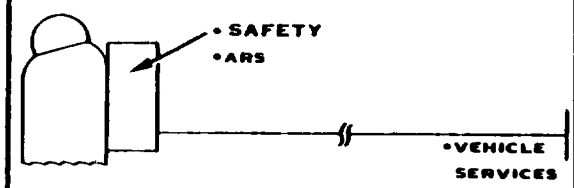
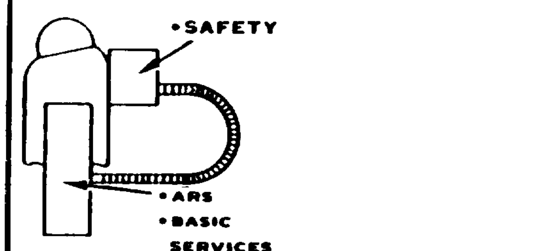
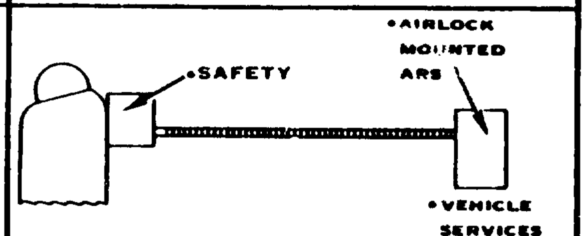
PACKAGING CONCEPT	DEGREE OF INTEGRATION	UMBILICAL	ARS FUNCTIONS	BASIC SERVICES
1	Self-Contained - Min Vol	None	On-the-person	On-the-person
2	Self-Contained - TIM/TDM	None	On-the-person	On-the-person
3	Minimum Expendables	Short O_2 Makeup	On-the-person	Carry-along
4	Minimum Expendables	Short O_2 Makeup	On-the-person	Vehicle Services
5	Minimum Expendables	Long O_2 Makeup	On-the-person	Carry-along
6	Minimum Expendables	Long O_2 Makeup	On-the-person	Vehicle Services
7	Safety Functions	Short O_2 Vent	Carry-along	Carry-along
8	Safety Functions	Short O_2 Vent	Airlock Mounted	Vehicle Services

These system configuration concepts meet all the rational combinations of crewman and equipment locations discussed previously.

LSS SYSTEM CONFIGURATION CONCEPTS

SYSTEM	ON-THE-PERSON	UMBILICAL	CARRY-ALONG	VEHICLE INTERFACE	
1	SELF-CONTAINED (MINIMUM VOLUME) • SAFETY FUNCTIONS EMERGENCY COMM C&W • ARS FUNCTIONS CO_2 REMOVAL HUMIDITY CONTROL VENTILATION • BASIC SERVICES MAKE-UP O_2 COOLING POWER	NONE	NONE	NONE	
2	SELF-CONTAINED (TIM-TDM)	NONE	NONE	NONE	
3	MINIMUM EXPANDABLES • SAFETY • ARS FUNCTIONS	SHORT O_2 MAKE-UP • COMM • POWER • COOLING • MAKE-UP O_2 • 8 M LONG	BASIC SERVICES • POWER • COOLING • MAKE-UP O_2	NONE	
4	MINIMUM EXPENDABLES	SHORT O_2 MAKE-UP	NONE	VEHICLE SERVICES • POWER • COOLING • MAKE-UP O_2	

LSS SYSTEM CONFIGURATION CONCEPTS (CONT'D)

SYSTEM	ON-THE-PERSON	UMBILICAL	CARRY-ALONG	VEHICLE INTERFACE	
5	MINIMUM EXPENDABLES	LONG O_2 MAKE-UP • SAME AS SHORT O_2 MAKE-UP EXCEPT 35M LONG	BASIC SERVICES	NONE	
6	MINIMUM EXPENDABLES	LONG O_2 MAKE-UP	NONE	VEHICLE SERVICES	
7	SAFETY FUNCTIONS	SHORT VENT • COMM • POWER • COOLING • VENT FLOW • 8M LONG	BASIC SERVICES ARS FUNCTIONS • VENT FLOW • CO_2 REMOVAL • HUMIDITY CONTROL	NONE	
8	SAFETY FUNCTIONS	SHORT VENT	NONE	VEHICLE SERVICES VEHICLE-MOUNTED ARS • VENT FLOW • CO_2 REMOVAL • HUMIDITY CONTROL	

LSS PACKAGING RECOMMENDATION

In the future, construction work is expected to become differentiated, so that certain people will work regularly at fixed worksites, tending machines and berthing payloads, while others will have more mobile assignments, assembling modules, activating, and servicing. Still others will have free-flying assignments, inspecting, repairing or coping with unforseen situations. Thus the ability to configure the ECWS to support work at fixed worksites, as well as to support mobile and free-flying tasks, is important.

The sensitivity analysis shows that system packaging concepts using minimum expendables on-the-person, 25 foot O_2 makeup umbilical, with basic services either carried along (Concept 3) or vehicle supplied (Concept 4) are the best choices for general purpose work. Concept 3 offers complete flexibility of worksite locations, with the ability to shed mass and volume when desirable. Concept 4 allows low EVA volume and mass by relying on vehicle services, and is thus well suited for work at long term established worksites. Transit to these worksites involves using a long O_2 makeup umbilical in the translation corridor, then connecting to a short O_2 makeup umbilical at the worksite to use vehicle services provided there.

The sensitivity analysis also shows that packaging configuration Concept 2, the self-contained TIM/TDM concept, has promise, and is recommended for consideration for free-flying tasks.

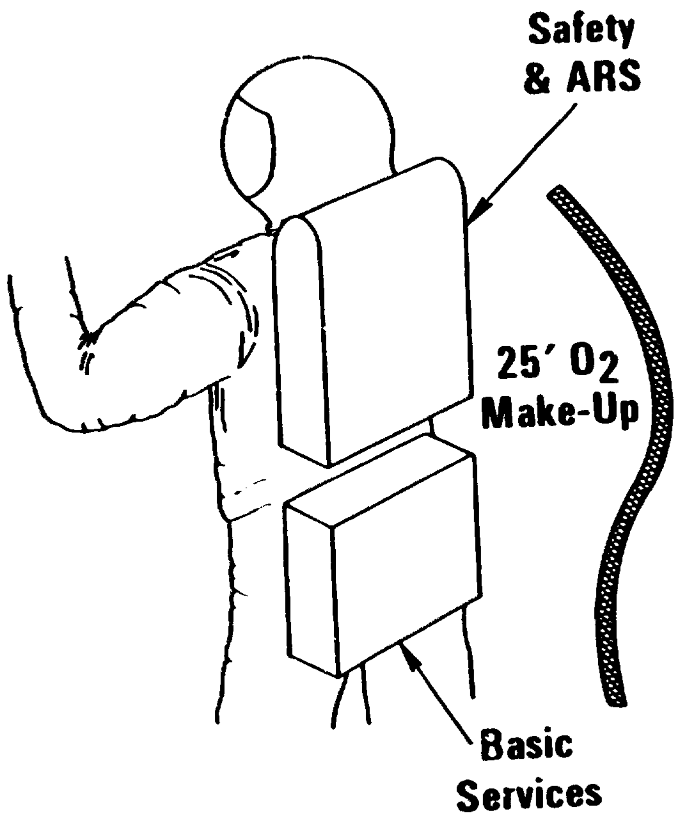
All three packaging concepts use the same LSS modules, except for the TIM/TDM concept, which does not use an O_2 makeup umbilical. It is recommended that the LSS be configured as <u>one</u> concept, a self-contained Safety and ARS package, (TIM), and having the option of adding a TDM that <u>is</u> either close-coupled (no umbilical) or umbilical-connected. This is "convertible" packaging.

The concepts using the 115 foot umbilical at the worksite were downrated for umbilical management reasons.

The concepts using the 25-foot O_2 vent umbilical were downrated because of the requirement to use them within 25 feet of the airlock, and because of the safety hazard of damaging the umbilical, which, for these concepts, is part of the low pressure ventilation loop.

Details of the rating and evaluations and an illustration of convertible packaging are contained in the following pages.

CONVERTIBLE ECWS LSS PACKAGING



	Free Flying	Portable	Fixed Worksite
TIM	On the Person	On the Person	On the Person
Umbilical	N/R	To TDM	To Vehicle Services
TDM	Close Coupled	Carry-Along	N/R

PRIMARY SELECTION

Space Station Program Phase

Extended Dimension Orbiter

	Volume						Flexibility				Reliability		
	On-the-Person Value	On-the-Person Rating	Carry-Along Value	Carry-Along Rating	Total Rating	0.4 Weighted Rating	Activity Rating	Duration Rating	Total Rating	0.3 Weighted Rating	Reliability Rating	0.3 Weighted Rating	Total Weighted Rating
		7		3	10	4	8	2	10	3	10	3	10
System 1	3.3	2.4	–	–	2.4	0.96	8	0	8	2.4	3	0.9	4.26
2	3.8	1.7	–	–	1.7	0.68	8	1	9	2.7	3	0.9	4.28
3	2.0	4.2	1.5	1.9	6.1	2.44	8	1	9	2.7	2	0.6	5.74
4	2.0	4.2	0.1	2.9	7.1	2.84	3	2	5	1.5	5	1.5	5.84
5	2.3	3.8	1.8	1.7	5.5	2.20	8	1	9	2.7	1	0.3	4.20
6	2.3	3.8	0.4	2.7	6.5	2.60	4	2	6	1.8	4	1.2	5.60
7	1.4	5	2.9	0.1	5.1	2.04	8	1	9	2.7	0	0	4.74
8	1.4	5	0.5	2.6	7.6	3.04	1	2	3	0.9	3	0.9	4.84

Free Flying Modules

	Volume						Flexibility				Reliability		
	On-the-Person Value	On-the-Person Rating	Carry-Along Value	Carry-Along Rating	Total Rating	0.3 Weighted Rating	Activity Rating	Duration Rating	Total Rating	0.4 Weighted Rating	Reliability Rating	0.3 Weighted Rating	Total Weighted Rating
		7		3	10	3	8	2	10	4	10	3	10
System 1	3.3	2.4	–	–	2.4	0.72	8	0	8	3.2	3	0.9	4.82
2	3.8	1.7	–	–	1.7	0.47	8	1	9	3.6	3	0.9	4.08
3	2.0	4.2	1.5	1.9	6.1	1.83	8	1	9	3.6	2	0.6	6.03
4	2.0	4.2	0.1	2.9	7.1	2.18	3	2	5	2.0	5	1.5	5.63
5	2.3	3.8	1.8	1.7	5.5	1.65	8	1	9	3.6	1	0.3	5.55
6	2.3	3.8	0.4	2.7	6.5	1.95	4	2	6	3.6	4	1.2	5.55
7	1.4	5	2.9	0.1	5.1	1.53	8	1	9	3.6	0	0	4.13
8	1.4	5	0.5	2.6	7.6	2.28	1	2	3	1.2	3	0.9	4.38

PRIMARY SELECTION (CONT'D)

Space Station Program Phase

Space Station

		Volume					Flexibility				Reliability		
		On-the-Person Value	On-the-Person Rating	Carry-Along Value	Carry-Along Rating	Total Rating	0.2 Weighted Rating	Activity Rating	Duration Rating	Total Rating	0.4 Weighted Rating	Reliability Rating	0.4 Weighted Rating	Total Rating
			7		3	10	2	8	2	10	4	10	4	10
System	1	3.3	2.4	–	–	2.4	0.48	8	0	8	3.2	3	1.2	4.88
	2	3.8	1.7	–	–	1.7	0.34	8	1	9	3.6	3	1.2	5.14
	3	2.0	4.2	1.5	1.9	6.1	1.22	8	1	9	3.6	2	0.8	5.62
	4	2.0	4.2	0.1	2.9	7.1	1.42	3	2	5	2.0	5	2.0	5.42
	5	2.3	3.8	1.8	1.7	5.5	1.11	8	1	9	3.6	1	0.4	5.11
	6	2.3	3.8	0.4	2.7	6.5	1.30	4	2	6	2.4	4	1.6	5.3
	7	1.4	5	2.9	0.1	5.1	1.02	8	1	9	3.6	0	0	4.62
	8	1.4	5	0.5	2.6	7.6	1.52	1	2	3	1.2	3	1.2	3.92

Large Structure Construction

		Volume						Flexibility				Reliability		Operability				
		On-the-Person Value	On-the-Person Rating	Carry-Along Value	Carry-Along Rating	Total Rating	0.2 Weighted Rating	Activity Rating	Duration Rating	Total Rating	0.3 Weighted Rating	Reliability Rating	0.4 Weighted Rating	Controls Rating	Transit Rating	Total Rating	0.1 Weighted Rating	Total Rating
			7		3	10	1	8	2	10	3	10	4	6	4	10	1	10
System	1	3.3	2.4	–	–	2.4	0.48	8	0	8	2.4	3	1.2	2	6	8	0.8	4.88
	2	3.8	1.7	–	–	1.7	0.34	8	1	9	2.7	3	1.2	3	6	8	0.8	5.04
	3	2.0	4.2	1.5	1.9	6.1	1.32	8	1	9	2.7	2	0.8	1	4	5	0.5	5.22
	4	2.0	4.2	0.1	2.9	7.1	1.42	3	2	5	1.5	5	2.0	3	4	7	0.7	5.62
	5	2.3	3.8	1.8	1.7	5.5	1.10	8	1	9	2.7	1	1.1	1	0	1	0.1	4.30
	6	2.3	3.8	0.4	2.7	6.5	1.30	4	2	6	1.8	4	6.6	3	9	3	0.3	5.00
	7	1.4	5	2.9	0.1	5.1	1.02	8	1	9	2.7	0	0	1	8	3	0.3	4.02
	8	1.4	5	0.5	2.6	7.6	1.52	1	2	3	0.9	3	1.2	10	2	2	0.2	3.82

SECONDARY SELECTION

Space Station Program Phase

EDO, Free Flying Modules, Space Station

	Weight						Operability				Maintainability				
	On-the-Person Value	On-the-Person Rating	Carry-Along Value	Carry-Along Rating	Total Rating	0.3 Weighted Rating	Controls Rating	Transit Rating	Total Rating	0.4 Weighted Rating	Repair Access	Replacement	Total Rating	0.3 Weighted Rating	Total Weighted Rating
		8		2	10	3	6	4	10	4	4	6	10	3	
System															
1	149	2.0	–	–	2.0	0.6	2	6	8	3.2	0	0	0	0	3.8
2	159	1.6	–	–	1.6	0.48	2	6	8	3.2	1	2	3	0.9	4.58
3	63	5.5	102	0.7	6.2	1.86	1	4	5	2.0	1	2	3	0.9	4.76
4	63	5.5	8	1.9	7.4	2.22	3	4	7	2.8	2	5	7	2.1	7.12
5	76	5.0	115	0.6	5.6	1.68	1	0	1	0.4	1	2	3	0.9	2.98
6	76	5.0	21	1.7	6.4	2.01	3	0	3	1.2	2	5	7	2.1	5.31
7	47	6.1	133	0.3	4.4	1.92	1	2	3	1.2	1	2	3	0.9	4.02
8	47	6.1	14	1.8	7.9	2.37	0	2	2	0.8	3	5	8	2.4	5.57

Large Scale Construction

	Weight						Maintainability				
	On-the-Person Value	On-the-Person Rating	Carry-Along Value	Carry-Along Rating	Total Rating	0.5 Weighted Rating	Repair Access	Replacement	Total Rating	0.5 Weighted Rating	Total Weighted Rating
		8		2	10	5	4	6	10	5	10
System											
1	149	2.0	–	–	2.0	1.0	0	0	0	0	1.0
2	159	1.6	–	–	1.6	0.8	1	2	3	1.5	2.3
3	63	5.5	102	0.7	6.2	3.1	1	2	3	1.5	4.6
4	63	5.5	8	1.9	7.4	3.7	2	5	7	3.5	7.2
5	76	5.0	115	0.6	5.6	2.8	1	2	3	1.5	4.3
6	76	5.0	21	1.7	6.4	3.35	2	5	7	3.5	6.85
7	47	6.1	133	0.3	4.4	3.2	1	2	3	1.5	7.7
8	47	6.1	14	1.8	7.9	3.95	3	5	8	4	7.95

SYSTEM CONCEPT EVALUATION

Each of the system concepts was evaluated against the evaluation criteria. The specific findings follow:

Go/No-Go Evaluation

All systems passed the go/no-go evaluation. Three systems require special consideration:

- Systems 4 and 6, (Makeup O_2 umbilical systems using vehicle services) require access to vehicle services in the airlock to facilitate ingress/egress. When used at the worksite they would require reconnection to vehicle services located there, hence they require two makeup O_2 umbilicals. Each system, therefore, requires an additional 115 foot umbilical. Since this additional umbilical would be a carry-along only between the airlock and worksite, and would be stowed at the worksite, its presence would have no impact on EVA work at the worksite. Therefore, no penalty was assigned relative to EVA task support at the worksite.

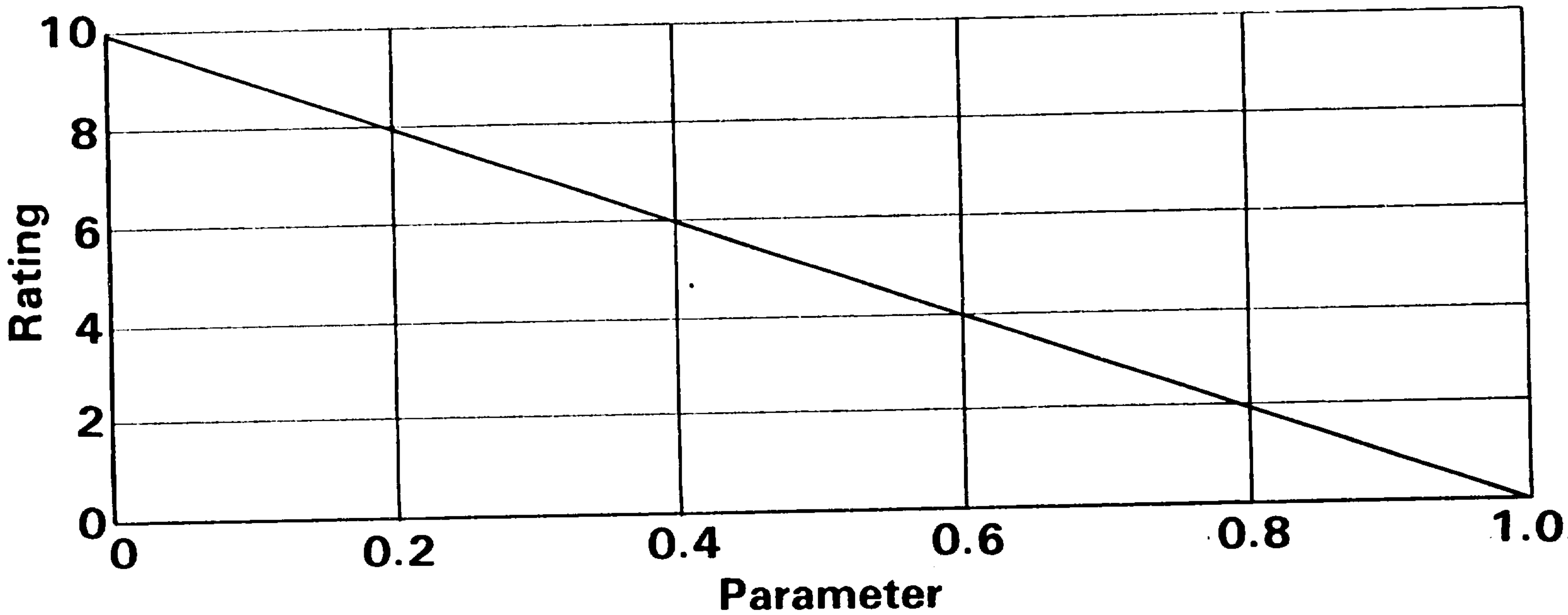
- System 8 (vent umbilical, using airlock-mounted ARS and vehicle services) is restricted to 25 feet from the airlock. Reconnection of the low pressure ventilation umbilical to another ARS at a worksite is forbidden, as this operation would violate the integrity of the ventilation loop in a vacuum.

RATING SCALES

Rating scales are used to convert weight and volume parameter assessments into a rating on a 0-10 point scale. The maximum point values occur for zero weight or volume. The minimum ratings occur for weight and volume evaluations just outside the range of the parameters studied. The rating scale for weights and volumes is shown in the accompanying illustration. The apportionment of rating points for the other primary and secondary evaluations is shown below:

EVA Volume	A two part issue:		
	On-the-person	5 ft^3 = 0 rating,	7 points
	Carry-Along	4 ft^3 = 0 rating,	3 points
		TOTAL	10 points
EVA Weight	A two part issue:		
	On-the-person	200 lbs = 0 rating,	8 points
	Carry-Along	160 lbs = 0 rating,	2 points
		TOTAL	10 points
Flexibility	A two part issue:		
	Ability to support activity in all locations		8 points
	Independence from fixed consummables		2 points
		TOTAL	10 points
Reliability	A three part issue defining unreliabilities associated with the presence or absence of major system segments:		
	Basic plus ARS functions		4 points
	Basic Services		3 points
	Umbilical		3 points
		TOTAL	10 points

WEIGHT AND VOLUME RATING SCALE



Parameter End Point

EVA Vol.	0 Rating =	5 Ft^3 On-the-Person 4 Ft^3 Carry-Along
EVA Wt.		200 Lbs On-the-Person 160 Lbs Carry-Along

RATING SCALES (Continued)

Maintainability	A two part issue:		
	Access for repairs		4 points
	Ease of expendables replacement		6 points
		TOTAL	10 points
Operability	A two part issue:		
	Freedom from attention during transit		6 points
	Ease of making LSS adjustments during EVA		4 points
		TOTAL	10 points

REPRESENTATIVE EVA LSS VOLUME AND WEIGHTS

Representative values of the LSS configuration concept element volumes and weights were generated in order to support numerical evaluation of weight and volume.

Volume - The accompanying illustration contains the volume makeup of the eight system configurations and the elements that comprise them.

As expected the primary volume driver is the ability to shed volume by using vehicle services, by vehicle-mounting the ARS, or by transferring volume from on-the-person to a carry-along location. The second driver is integrated approach and the third driver is umbilical type packaging.

Weight - The illustration also contains the weight makeup of the eight system concepts and the elements that comprise them.

As expected the primary weight driver is the ability to shed weight by using vehicle services to eliminate the basic services package. The second driver is the packaging of the integrated concepts for maintenance.

REPRESENTATIVE WEIGHT AND VOLUME OF EVA LIFE SUPPORT SYSTEM ELEMENTS

ELEMENT	MODULAR DIMENSIONS INCHES	VOLUME FT^3	WET WEIGHT LBS
SAFETY FUNCTIONS PACKAGE ON-THE-PERSON • EMERGENCY • COMMUNICATIONS • CAUTION & WARNING	21 X 9 X 8	0.9	33
ARS FUNCTIONS PACKAGE ON-THE-PERSON OR CARRY-ALONG • HUMIDITY CONTROL • CO_2 REMOVAL • VENTILATION	21 X 9 X 9	1.0	22
BASIC SERVICES PACKAGE ON-THE-PERSON OR CARRY-ALONG • POWER • COOLING • MAKE-UP O_2	21 X 9 X 13	1.4	94
INCREMENTAL PACKAGING PENALTY FOR TIM/TDM CONFIGURATION • WEIGHT 7% • VOLUME 15%	21 X 9 X 5	0.5	10
SHORT VENTILATION UMBILICAL (25 FEET) • TETHER • COMMUNICATIONS • POWER • COOLING • VENTILATION FLOW • STORAGE REEL	3-1/2 X 1-1/2 CROSS SECTION	1.0	28
SHORT O_2 MAKE-UP UMBILICAL (25 FEET) • TETHER • COMMUNICATIONS • POWER • COOLING • MAKE-UP O_2 • STORAGE REEL	1 X 1 CROSS SECTION	0.2	16
LONG O_2 MAKE-UP UMBILICAL (100 FEET) • TETHER • COMMUNICATIONS • POWER • COOLING • MAKE-UP O_2 • STORAGE REEL	1 X 1 CROSS SECTION	0.8	42

REPRESENTATIVE EVA SYSTEM WEIGHTS AND VOLUMES

System →	1 Vol	1 Wt	2 Vol	2 Wt	3 Vol	3 Wt	4 Vol	4 Wt	5 Vol	5 Wt	6 Vol	6 Wt	7 Vol	7 Wt	8 Vol	8 Wt
Basic Functions Pkg ARS Functions Pkg Basic Services Pkg Pkg Penalty 1/2 Umbilical	0.9 1.0 1.4 – –	33 22 94 – –	0.9 1.0 1.4 0.5 –	33 22 94 10 –	0.9 1.0 – – 0.1	33 22 – – 8	0.9 1.0 – – 0.1	33 22 – – 8	0.9 1.0 – – 0.4	33 22 – – 21	0.9 1.0 – – 0.4	33 22 – – 21	0.9 – – – 0.5	33 – – – 14	0.9 – – – 0.5	33 – – – 14
With-The-Person Tot.	3.3	149	3.8	159	2.0	63	2.0	63	2.3	76	2.3	76	1.4	47	1.4	47
1/2 Umbilical Basic Expendables ARS Functions	– – –	– – –	– – –	– – –	0.1 1.4 –	8 94 –	0.1 – –	8 – –	0.1 1.4 –	21 94 –	0.4 – –	21 – –	0.5 1.4 1.0	14 94 25	0.5 – –	14 – –
Carry-Along Total	–	–	–	–	1.5	102	0.1	8	1.8	115	0.4	21	2.9	133	0.5	14
Total	3.3 Ft^3	149 Lb	3.8	159	3.5	165	2.1	71	4.1	191	2.7	97	4.3	180	1.9	61
Rank – Vol. – Wt.	4	4	6	5	5	6	2	2	7	8	3	3	8	7	1	1

FLEXIBILITY

As seen, the primary driver is location restriction as determined by the absence or presence of vehicle services. The second level driver is the ability to tailor expendables used to actual mission requirements. The third level driver is the degree of restriction to certain locations.

FLEXIBILITY RATING

	Activity				Duration			Total
	25′ of A/L 1	25′of Crane or Worksite 3	115′ of Crane or Worksite 4	Anywhere 8	Self-Contained Expendables Fixed 0	Self-Contained Expendables Some Variable 1	Some Vehicle Supplies 2	Flexibility
System								
1				8	0			8
2				8		1		9
3				8		1		9
4		3					2	5
5				8		1		9
6			4				2	6
7				8		1		9
8	1						2	3

RELIABILITY

The reliability rating is associated with the unreliability due to the presence or absence of the basic service package and the umbilical type. The primary driver in reliability is the absence of the basic services package in those system concepts that use vehicle-supplied services. The secondary driver is seen to be the presence and type of umbilical used.

RELIABILITY RATING

	Carry-Along/ On-the-Person		Umbilical				
	• Safety Pkg • ARS Pkg	• Basic Services Pkg	Long O_2	Short O_2	Short Vent	Total Unrel	Rel
System	4	3	2	1	3		
1	4	3	–	–	–	7	3
2	4	3	–	–	–	7	3
3	4	3	–	1	–	8	2
4	4	–	–	1	–	5	5
5	4	3	2	–	–	9	1
6	4	–	2	–	–	6	4
7	4	3	–	–	3	10	0
8	4	–	–	–	3	7	3

Reliability = 10 – Σ Unreliabilities

MAINTAINABILITY

The illustration shows the maintainability evaluation. This evaluation is based upon the relative number of packages in a system concept and their complexity. A system, consisting of one inseparable, integrated package, has less access and is more difficult to service than system concepts that do not require a basic services package or that use two packages, thus providing maintenance access from several surfaces.

As expected the primary driver is the presence or absence of the basic services package, the absence of which eliminates a significant portion of the LSS requiring maintenance of any kind. The second driver is the ARS packaging, the more tightly integrated, the more difficult the maintenance. The third driver is the packaging of the integrated system, either separable into a TIM/TDM, or left as a single, monolithic package.

MAINTAINABILITY RATING

	Access for Repairs – Unaccessability Factors: On-the-Person				Access for Repairs – Unaccessability Factors: Carry-Along			Access for Consummables Replenishment – Unreplenishability Factors: All Expendables		CO_2 Only	None		
	Full-Up • Safety • ARS • Basic Serv	Full-Up • Safety • ARS • Basic Serv (TIM-TDM)	Min Exp • Safety • ARS	Safety	Basic Services	Basic Services Plus ARS	Access Rating	Integrated	TIM-TDM or Separate Packages			Expendable Replacement Rating	Total Rating
System	4	3	2	1	1	2	4	6	4	1	0	6	10
1	4						0	6				0	0
2		3					1		4			2	3
3			2		1		1		4			2	3
4			2				2			1		5	7
5			2		1		1		4			2	3
6			2				2			1		5	7
7				1		2	1		4			2	3
8				1			3			1		5	8

Accessibility = 4 – Unaccessability

Replenishability = 6 – Unreplenishability

OPERABILITY

The operability evaluation, is based upon controls location and umbilical management considerations. The locations of controls can be (a) in-the-vehicle (which are very accessible), (b) on-the-person (which require actuation by the crewman), and (c) remotely located on a carry-along package (which require interruption of a task to go over to the package to perform the adjustment). Umbilical management arises during translation to, from and about a worksite, and is affected by the length and stiffness of the umbilical. The short O_2 makeup umbilical is the easiest to handle, the vent umbilical is intermediate, and the long O_2 umbilical is the most difficult. The ranking of the system concepts for operability is as follows:

The primary driver is presence or lack of umbilical which defines the controls as being either all on-the-person or some located remotely. The second driver is the type of umbilical which defines if ARS and/or Basic Services controls are located remotely, and the third driver is the presence or absence of vehicle basic services, which defines if those controls are in the vehicle or remote from the crewman.

OPERABILITY RATING

	Controls Location						Umbilical Management					
	All in Vehicle	Some in Vehicle	All on Crewman	Some Remote on Carry-Along	Some in Air Lock	Total Rating	None	Short O_2	Short Vent	Long O_2	Umb Mgmt Rating	Total Rating
System	4	3	2	1	6	4	6	4	2	0	6	10
1			2			2	6				6	8
2			2			2	6				6	8
3				1		1		4			4	5
4		3				3		4			4	7
5				1		1				0	0	1
6		3				3				0	0	3
7				1		1			2		2	3
8					0	0			2		2	2

ECWS EVA ENCLOSURE AND WORKAIDS

- Pressure Enclosure
- Hazards Protection
- Helmet
- Gloves
- Tool Adapters
- Workstand

ECWS EVA ENCLOSURE

A practical space construction capability imposes several requirements on the EVA enclosure not required of the Shuttle EMU. Specifically, the Shuttle EMU SSA life requirements are 6 years of calendar time and 7,000 to 100,000 flex cycles for joints, depending on joint type. ECWS, by contrast, requires approximately up to 500,000 cycles on certain joints over a single 180 day mission, and it is desirable that joints last for 10 such missions, thus requiring 5,000,000 cycles over a 10 year period.

A fundamental ECWS objective is to eliminate prebreathe prior to EVA. This requires a minimum ECWS pressure of 4 psia if the space station is at 9 psia, or an ECWS pressure of 8 psia if the space station is at 14.7 psia. The space station pressure has not yet been established, although MDAC recommended 8 psia in the SSSAS reports. Thus ECWS is being concepted for 4 psia and 8 psia operation. By contrast, the Shuttle EMU was designed for 4 psia operation only and requires the EVA crew to prebreathe for 3 hours prior to each EVA.

Shuttle payload characteristics have already been defined in terms of maximum edge sharpness, freedom from burrs and other parameters that reduce puncturing, tearing or abrasion of the EMU SSA. These are achievable characteristics because Shuttle payloads or their structural elements are fabricated on earth, and are finished prior to launch. They will require only assembly or deployment in orbit. ECWS, on the other hand, will be involved with fabrication and repair of structural elements in orbit, which implies handling of unfinished or damaged elements, with their attendant rough surfaces and sharp edges. In addition, use of cutting, drilling and fastening tools is anticipated, which increases the risk of damage to the EVA enclosure.

Potential construction orbits, coupled with projected EVA levels, pose radiation hazards not encountered with the Shuttle EMU. ECWS design must consider radiation protection for high inclination LEO and GEO EVA.

Helmet design should consider wide angle viewing and hands-off visoring to permit efficient construction in an environment where lighting levels can change from full sun to full shadow almost instantaneously, and where members of EVA work teams must retain visual contact with each other.

ECWS EVA ENCLOSURE (Continued)

While small bladder leaks can be repaired in the Shuttle EMU SSA, it is not planned to perform these repairs on-orbit. Present planning calls for limiting on-orbit repairs to PLSS/DCM changeout, interchange of quick disconnectable items, and possible arm changeout, as limited by compatible scye bearing sizes. The SSA torso can also be lengthened by 1 inch to account for the spinal decompression that occurs during the first week in orbit and vernier length adjustments can be made to the arms and legs for comfort. The ECWS EVA enclosure, on the other hand, will require an on-orbit maintenance capability that includes the possibility of replacing any damaged element such as joints, interjoint sections, and gloves, or change out of tool adapters.

In addition, to retain long term comfort, the ECWS EVA enclosure will require an additional lengthening of the torso to accommodate the further spinal decompression that occurs after the first week in orbit.

The long ECWS missions will complicate the maintenance of EVA enclosure hygiene, in the sense of keeping the EVA enclosure acceptable to the crewmen. Specific problems will be to maintain the EVA enclosure free of unpleasant odor, and free of detritus shed from the surface of the crewman's body. The problem is further complicated by the potential for the enclosure being worn by different crewman during a 180 day mission.

Present Shuttle space practice calls for swabbing out the SSA and drying it after each EVA and disinfecting the LCVG by squeezing it with a disinfectant-treated towel. The leading disinfectant agent candidate is a quaternary ammonium compound, currently used in the dairy industry. After a maximum of 6 EVA's the SSA will be returned to earth, cleaned, and then sized for the next mission. The LCVG will be laundered on earth after a maximum of 6 EVA's. During ECWS missions the enclosures may be returned to earth only every 180 days, after upwards of 154-8-hour EVA's. Hence, EVA enclosure hygiene must receive careful consideration to maintain enclosure cleanliness levels that are acceptable to the crewman and present no biological hazard to the crew over the long duration of these missions.

The above considerations are the major reasons why ECWS require an advanced EVA enclosure design.

ECWS PRESSURE ENCLOSURE REQUIREMENTS

The following requirements define the basic performance and operating requirements to guide the concepting of the ECWS EVA pressure enclosure.

1. <u>General</u>

   The EVA pressure enclosure shall retain a habitable environment around one EVA crewman, and shall permit performing of EVA tasks without requiring the use of manipulators or remote teleoperators. The EVA enclosure shall be comfortable, have high reliability, require low maintenance, and be low in weight and volume consistent with the following requirements.

2. <u>Life</u>

   ECWS enclosures to support 180 day missions shall have a maximum joint cyclic life of 5 million cycles over a period of 10 calendar years and 10 missions. This is consistent with:

   $$\frac{6\ \text{joint cycles}}{\text{minute}} \times \frac{60\ \text{minutes}}{\text{EVA hour}} \times \frac{1{,}232\ \text{EVA hours}}{\text{mission}} \times 10\ \text{missions} = 4{,}435{,}200\ \text{joint cycles}$$

   This applies to the high-use joints of the upper torso and arms. Other joints will require fewer cycles.

   Static elements shall have a life of 10 calendar years.

   Disconnect items shall have a cyclic life of 2,000 cycles. This is consistent with:

   $$\frac{1\ \text{don-doff cycle}}{\text{EVA Sortie}} \times \frac{6\ \text{EVA Sorties}}{7\ \text{Days}} \times \frac{180\ \text{days}}{\text{mission}} \times 10\ \text{missions} = 1{,}543\ \text{cycles}$$

ECWS PRESSURE ENCLOSURE REQUIREMENTS

3. Pressure Level

EVA pressure level shall be a nominal 4 psia of pure O_2 or 8 psia of O_2/N_2.

4. Leakage

The EVA enclosure leakage shall not exceed 30 scc/minute at 4.0 psia.

5. EVA Pressure Enclosure Mobility Requirements

The Pressure Enclosure shall provide the following range of motions as a minimum. The maximum torque values accompanying the motion shall be as specified. The torque values denoted by * shall be reduced as feasible to minimize crewman fatigue.

Joint Motion	Minimum Mobility Range, Degrees	Maximum Torque, Ft-Lb
Shoulder-Lateral	150	1.0
Shoulder-Medial	20	1.0
Shoulder-Extension	180	1.8*
Shoulder-Flexion	180	1.8*
Shoulder Rotation (x-z plane)	90	0.5
Shoulder Adduction	150	1.0
Shoulder Abduction	150	1.0
Shoulder Rotation (y-z plane)	120	2.5*
Elbow Flexion/Extension	130	1.0
Forearm Supination	75	0.5
Forearm Pronation	75	0.5
Wrist Extension	90	0.5*
Wrist Flexion	90	0.5*
Wrist Adduction	30	0.5*
Wrist Abduction	20	0.5*
Wrist Rotation	180	0.8*
Hip/Waist Flexion	75	4.0
Waist/Spine Rotation	150	9.2

Joint Motion	Minimum Mobility Range, Degrees	Maximum Torque, Ft-Lb
Hip Flexion	70	2.0
Hip Abduction	10	2.0
Knee Mobility (Standing Flexion)	110	1.0
Knee Mobility (Forced Flexion)	150	1.0
Ankle Flexion	40	1.0
Ankle Extension	40	1.0

7. EVA Enclosure Drinking Provisions

The ECWS drink bag shall allow convenient crewman drinking while preventing inadvertent activation of the drink valve. The bag shall be capable of being microbiologically cleaned and shall hold a minimum of 24 fluid ounces to support 8 hours of EVA. This is consistent with the Shuttle EMU requirement of 21 oz for a 7 hour EVA.

The materials used shall not impart any off-taste flavor to the drink.

8. Waste Management

The ECWS shall receive and provide internal storage for 950 cc of urine while pressurized. The Urine Collection Device shall provide for the hygenic collection, storage and disposal of urine and shall be compatible with microbiological cleaning procedures. The UCD shall consist of a container worn inside the ECWS and a replaceable adapter employed as the crew-member interface.

9. Hygiene

EVA Enclosure design shall consider the fact that up to 154 8-hour EVA sorties may occur between return to earth. Therefore, the EVA enclosure design must promote levels of hygiene acceptable to the crewman. In addition the following specific requirements shall be:

- Non-Nutrient - Enclosure materials shall not support microbial growth.

- Odor Free - The EVA enclosure materials shall not absorb odors and shall be intrinsically odor-free.

- Post Sortie Servicing - Wipe down, freshening and drying shall require a maximum of 10 minutes.

10. Sizing

The following factors shall be considered relative to crewman comfort during repetitive, long EVA use.

- Enclosure design shall consider sizing to fit a large segment of the 1985 population such as the 5th to 95 percentile male and female crew members and members of an identified crew.

- On-Orbit Sizing shall include the provision for lengthening the torso to accommodate growth resulting from spinal decompression.

Requirements 4 through 10 are consistent with values previously established within the ECWS Study Program.

11. Workplace Hazards

- Impact - The crewman shall escape impact injury and joints shall continue to function after a collision at 5 ft/sec of a crewman with a total of 1000 lbs, consisting of the crewman, the ECWS, personal propulsion and work materials.

The above value is consistent with body force levels already established for projected ECWS tasks.

ECWS PRESSURE ENCLOSURE REQUIREMENTS (Continued)

12. On-Orbit Maintenance

To facilitate maintenance of the ECWS enclosure while on-orbit, the enclosure shall be modular in construction at least to the level of permitting replacement of individual limb and torso joints and limb interjoint elements.

13. Unassisted Donning and Doffing Capability

The ECWS EVA Enclosure shall be capable of being donned and doffed by the wearer without assistance from the other crewmen.

14. Other Requirements

Other requirements shall be consistent with the "Guidelines and Requirements Document of the ECWS Study Program" in Section 4 of this volume.

PRESSURE ENCLOSURE DEVELOPMENT ISSUES

The following areas of the ECWS pressure enclosure require development to meet the previously stated requirements.

- Joints
- Bearings and intermodule connections
- Entry closure
- Fabric module construction
- Leg mobility issues

These areas are discussed in turn in the following pages.

JOINTS

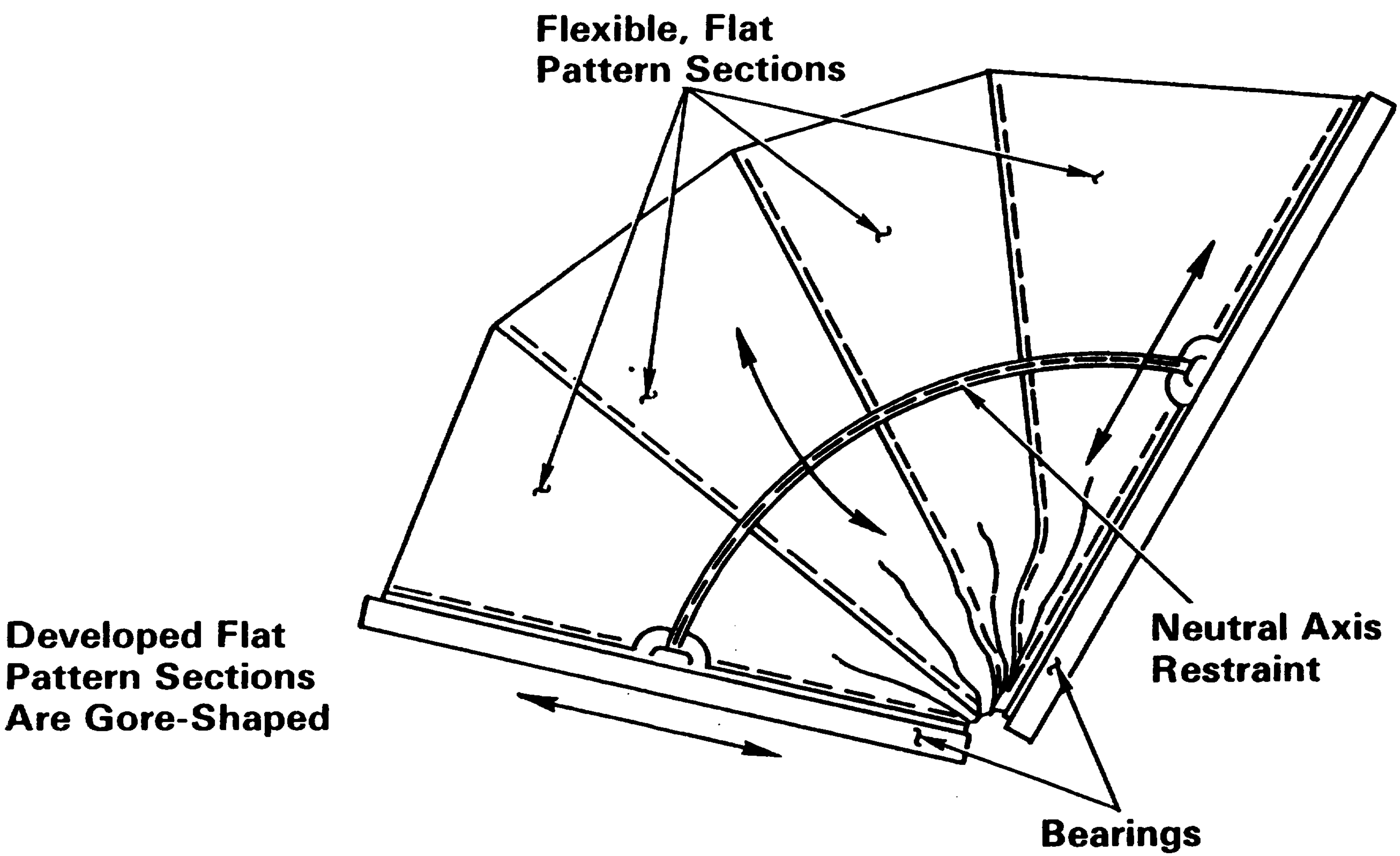
Four basic joint types have been developed for EVA enclosures to date. They are:

- Flat Pattern
- Rolling Convolute
- Torroidal
- Stove Pipe

Flat Pattern Joints - represent a low cost joint construction adequate for the Shuttle EMU program, which requires a joint life of 7,000 to 100,000 cycles, depending on the particular joint, at 4 psig operating pressure. These joints are constructed of flat, gore shaped fabric sections which are stitched together and sealed at the seams. When the joint is flexed, the fabric on the inside of the bend is allowed to pucker.

This concept achieves high mobility and low bulk, and is very inexpensive to manufacture. It is also highly resistant to impact damage. The chief disadvantage for long term ECWS use is life. It doubtful if these joints can be developed for the 5,000,000 cycle life required for long term ECWS use.

FLAT PATTERN JOINT

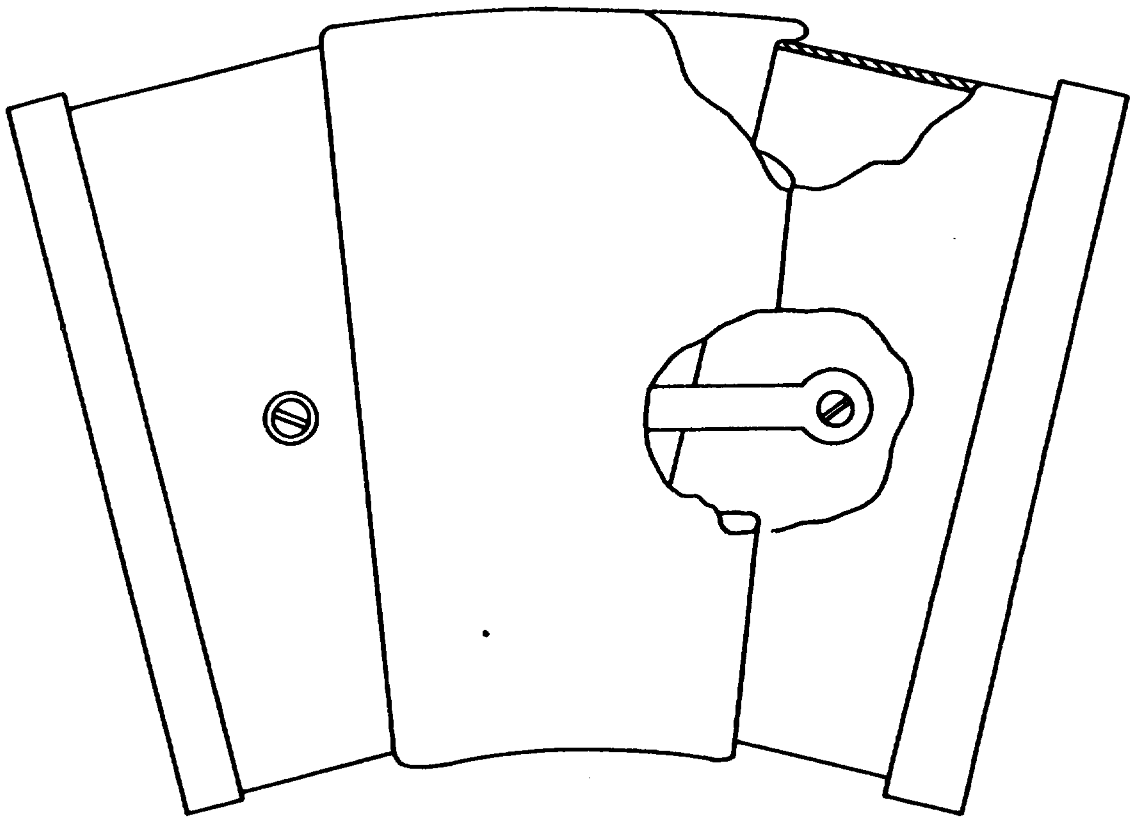


JOINTS (Continued)

Rolling Convolute Joints - Consists of a single convolute bellows construction, in which the bellows rolls over the hard end-section as the joint is flexed.

This concept achieves high mobility, and is amenable to stepped or tapered construction, which is desired for shoulder joints. The chief disadvantages are that it is bulkier, has shorter life, and is more impact sensitive than other concepts.

ROLLING CONVOLUTE JOINT



JOINTS (Continued)

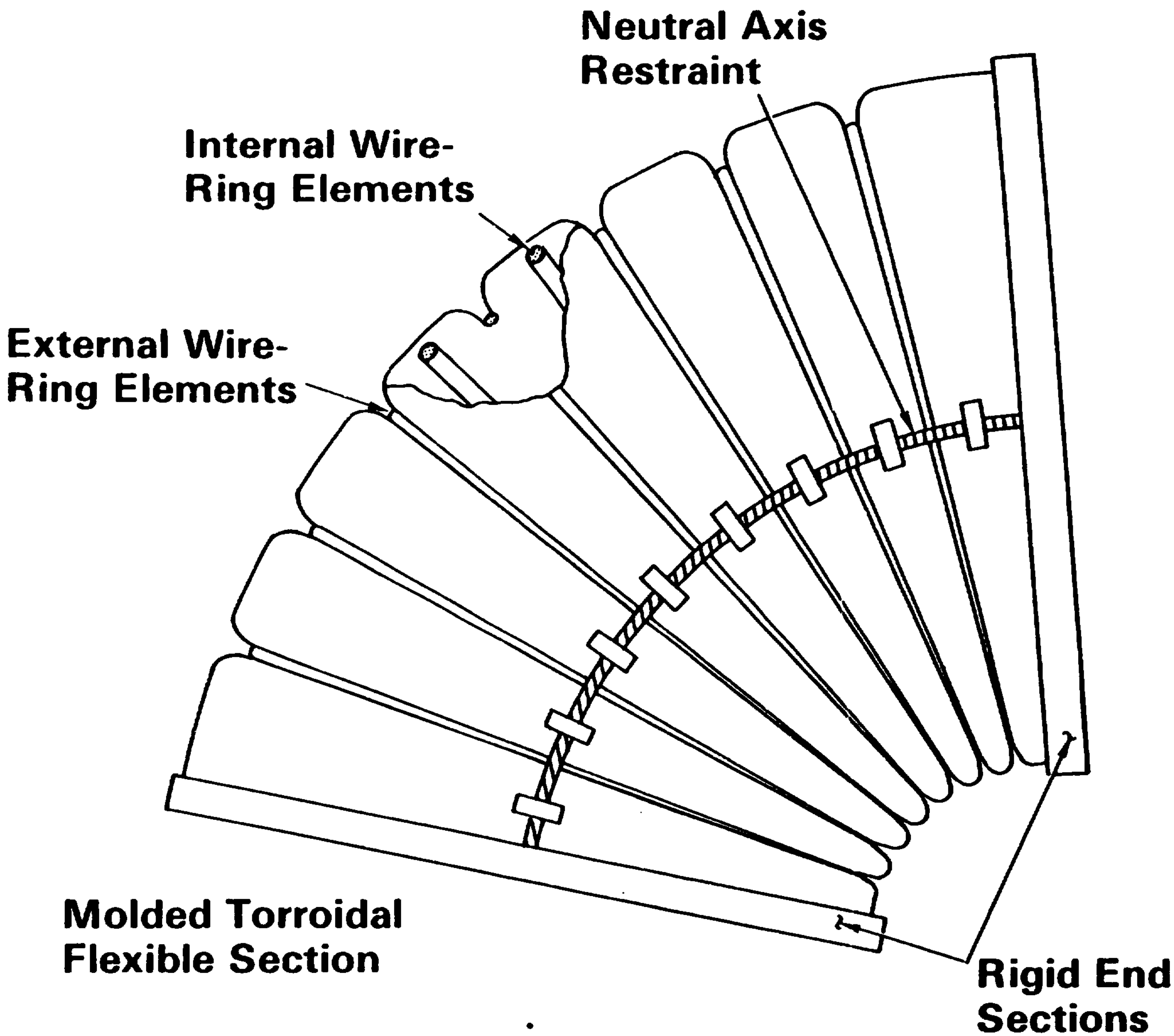
Toroidal Joints - Resemble a wire-reinforced molded bellows. External wire-ring elements keep the minor diameter portions from ballooning under pressure, and internal wire-ring elements keep the major diameter portions from collapsing under flexion. When the joint is flexed, the excess material on the inside of the bend is accompanied by a radial shift between the internal and external wire ring elements, which increases the difference between the major and minor radius, thus "swallowing" the excess material. On the outside of the bend the radial shift decreases the difference between major and minor radii, thus releasing material longitudinally to follow the longer outside curve. The toroidal joint flexes without puckering, which contributes to its long life and excellent flexibility.

The advantages of this concept are its very high flexibility and potential for long life. It is also very stowable, and has high impact resistance.

The chief disadvantages are high unit cost of manufacture, as it is of molded construction, and its bulk. It is a long joint when used for sharp bends.

The chief disadvantage for shoulder joint use is that it cannot be made tapered, because tapered torroidal joints tend to "bunch up" at the small end, owing to the area differential between the large and small ends, causing a loss flexibility and mobility range.

TORROIDAL JOINT



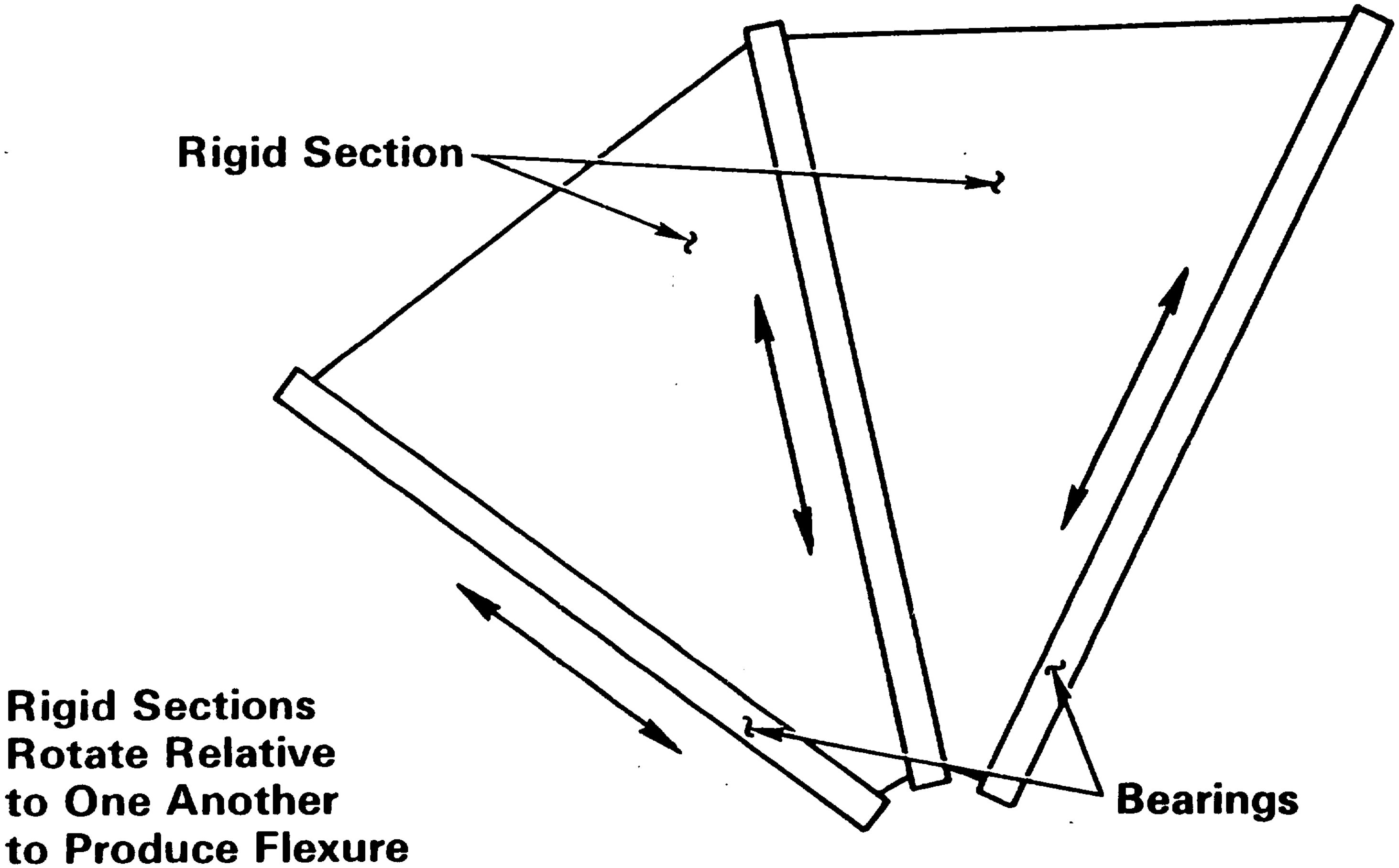
JOINTS (Continued)

Stove Pipe Joints - consist of obliquely-truncated cylindrical or conical elements, joined together by sealed bearings. Flexure is achieved by rotating the adjacent sections relative to one another. Flexure occurs when the force producing the flexure is resolved by the obliquely-mounted bearings causing the adjacent sections to rotate.

The advantages of this joint concept are its extremely long life, low cost, and the fact that it can be made in a tapered configuration, a singular requirement of shoulder joints, in that a minimum bulk design is desired. The scye bearing at the chest wall is large, to permit donning and doffing, while the upper arm bearing is smaller, to permit the arms to hang down freely, unencumbered by a large bearing diameter over the biceps.

The disadvantages of this concept are that the joint sections must be carefully designed to avoid "lock up", a configuration in which the flexion motion cannot be resolved to produce rotation. This requires subsequent programming of the motion sequence to free the joint. Current designs minimize this problem by employing at least three bearings. In addition, impact resistance must also be considered in the design because of the potential for knocking the sections out-of-round, thus restricting the relative rotation of adjacent joint sections.

STOVE PIPE JOINT



JOINTS RECOMMENDATIONS

The toroidal joint is the recommended implementation for all ECWS EVA enclosure joints, including the waist. The singular exception is in the shoulder, where a tapered configuration is required to reduce on-the-person volume.

The recommended development program for toroidal joints is to demonstrate 5,000,000 cycle life at 8 psig, and to reduce the manufacturing cost.

The recommended development program for the shoulder stove pipe joint consists of refining the design to minimize the motion-programming requirement, and to ruggedize the joint for impact resistance.

JOINT TYPE EVALUATION

	Flat Pattern	Rolling Convolute	Torroid	Stove Pipe
Performance				
Mobility	G	G	G	F
Life	P	F	G	G
Impact Resistance	G	F	G	F
EVA Volume	G	G	G Except Shoulder	G
Flexibility	F	G	G	G
Vehicle Volume	G	F	G	F
Cost	G	F	P	G
G = Good	F = Fair	P = Poor		

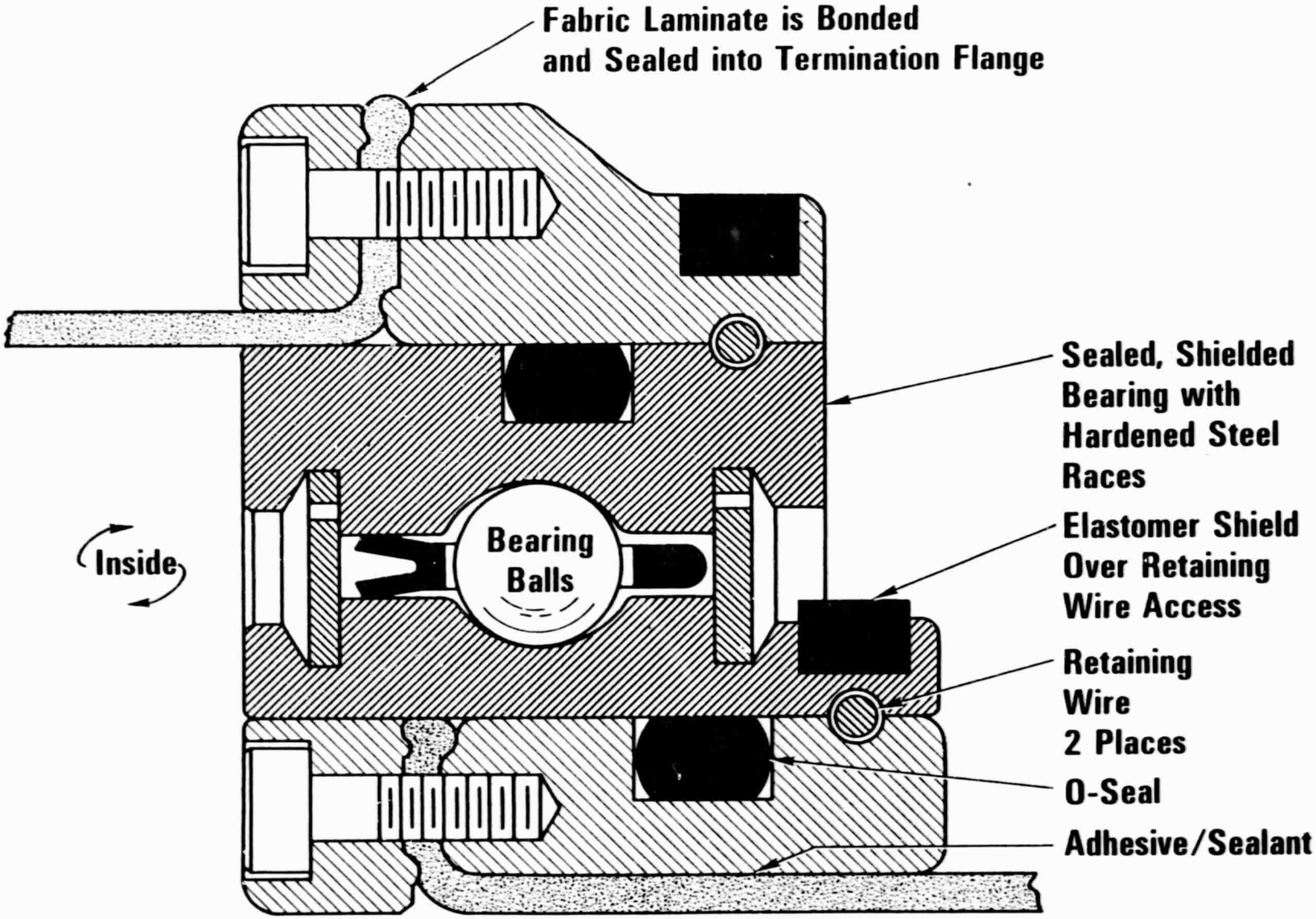
BEARINGS AND INTERMODULE CONNECTIONS

Bearings are required between joints, and, in the case of stove pipe joints, between the joint sections themselves. Bearings under current development have seals and ball spacers integrated into one piece. The bearings for ECWS should be hardened, forged, steel races, for smoothness of operation and to resist deformation under impact.

The intermodule bearing connection integrates the bearing into the fabric section termination. The retaining wire permits the bearing and/or fabric modules to be removed and replaced, if necessary. The bearing can be eliminated from modules not requiring bearings and replaced with a solid ring.

The recommended development program is to combine the bearing and intermodule connector into the joint development program for concurrent development of integrated joints and modules.

BEARING & INTERMODULE CONNECTION CONCEPT



ENTRY CLOSURE

Chief drivers in entry closure considerations are:

- Integration with life support equipment
- Don/doff ease
- Structural integrity

These drivers raise the following issues:

The safety functions of the LSS (communication, caution and warning, and emergency subsystem) must be worn with the crewman. To facilitate don/doff, it is desirable that these be permanently attached to the EVA enclosure. The ARS vent loop connections between the LSS and enclosure torso should also be permanent, and not made and broken during each EVA sortie.

Hard enclosure structure is desirable for mounting the LSS to EVA pressure enclosure for maximum structural integrity.

TIM LSS functions, which are permanently mounted to the enclosure, should be mounted to the upper torso rather than the lower torso to bring the LSS CG close to the crewman's CG, and to keep the LSS in close proximity to the EVA enclosure when the crewman bends forward at the waist. With the LSS attached at the lower torso, a gap will open up between the LSS and EVA enclosure when the crewman bends forward, which could impede access to tight areas.

Don/doff ease is facilitated by having scye bearings which can move during the donning process.

Two concepts have evolved for coping with these issues, the single-plane closure and the two-plane closure.

ENTRY CLOSURE (Continued)

The single-plane closure uses a primarily hard upper torso to mount the LSS components to be back and front, thus achieving reliable, fixed integration of the LSS and EVA enclosure, proper LSS and crewman CG location, and freedom from gap when the crewman bends forward. The scye bearings are soft-mounted to permit them to move, thus facilitating don/doff.

The two-plane closure uses a hard lower torso section with a high back. LSS components are mounted to the front and to the high back, achieving the reliable integration of the LSS components, proper CG relationship and freedom from gap between the LSS and EVA enclosure. The upper torso is soft, permitting easy don/doff.

Evaluation of the two concepts shows that while both concepts are acceptable for ECWS, the single-plane closure will be flight-ready sooner, and is a simpler, less costly, and a more reliable concept. Therefore, the single-plane closure is recommended for ECWS.

ENTRY CLOSURE EVALUATION

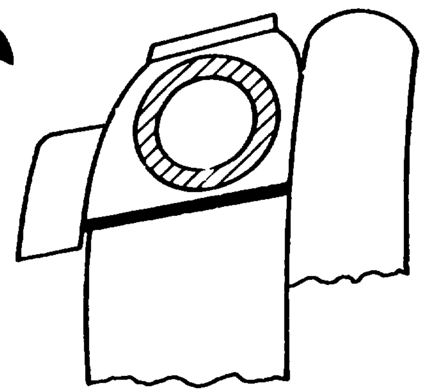
	Single-Plane	Two-Plane
Don/Doff	G	G
Availability	1980	1985-86
Comfort/Mobility	G	G
LSS Interface	G	G
Latching Effort	G	F
Seal Reliability	G	F
Cost	G	F

G = Good
F = Fair

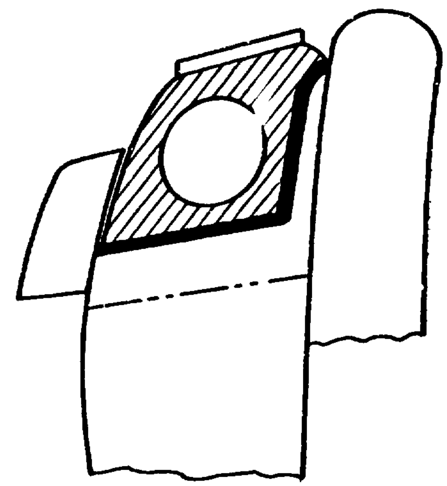
ENTRY CLOSURE

Single-Plane

Simpler,
More Reliable
Less Costly



Two-Plane



Torso	Single-Plane	Two-Plane
Upper	Hard with Movable Scye Bearings	Soft
Lower	Hard or Soft	Hard, High Back Upper Section

FABRIC MODULE CONSTRUCTION

Fabric joint and enclosure modules require pressure retention and restraint means, as well as abrasion and puncture resistance. Two concepts have been developed for fabric module wall construction, separate bladder and restraint, and single wall laminate.

Separate bladder and restraint construction consists of a bladder inside the separate restraint layer. When inflated, hoop tension in the restraint prevents ballooning of the bladder. Inner tube/tire combination is an analogy.

Single wall laminate construction bonds the bladder and restraint layers together to form a single layer. Tubeless tire is an analogy.

Evaluation of the two concepts shows that single wall laminate is expected to have superior life based upon freedom from chafing between the restraint and the bladder. High cycle life has already been demonstrated at the module level (in excess of 3 million cycles).

Single wall construction also exhibits greater snag and tearing resistance due to its greater local rigidity. Hence, it is less likely to "hang up" on a point or edge.

The ability to don and doff a single wall laminate is superior because the inner surface is smooth. Separate bladder and restraint construction tends to "bunch up" during don and doff. Hygiene maintenance is easier with single wall construction, as the inner surfaces are smooth. Freedom from bunching eliminates folds and wrinkles which are difficult to clean and dry.

Fabric section termination is also simpler with single wall construction, as just one layer requires termination at each end. Separate bladder and restraint construction requires two layers to be terminated at each end. The single termination simplifies module replacement on-orbit, and freedom from chafing extends life, reducing the need for on-orbit repairs. Hence, the single wall laminated construction is superior in maintainability.

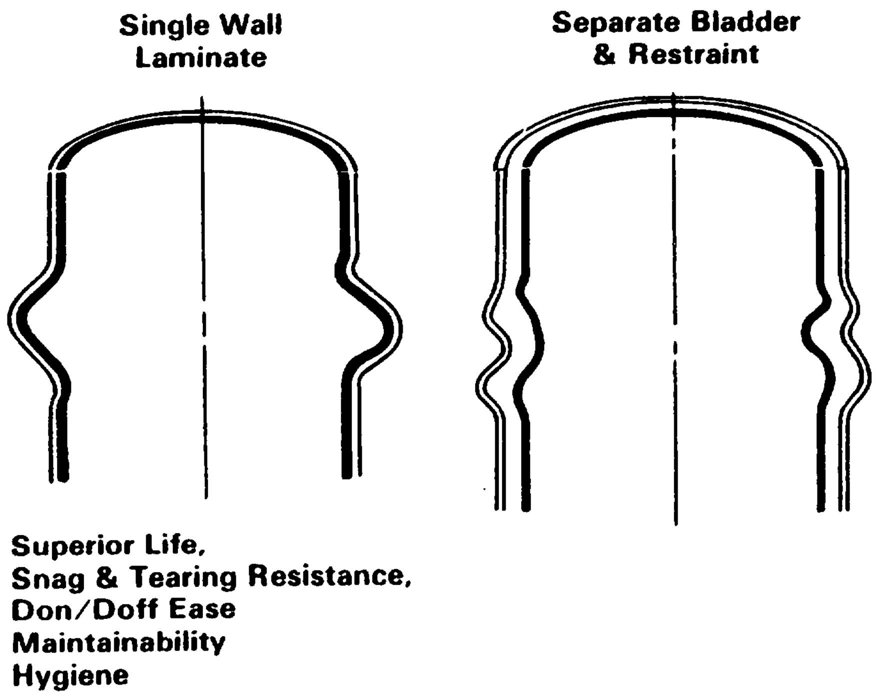
Thus, the recommended fabric wall construction for ECWS is single wall laminate.

FABRIC MODULE CONSTRUCTION (Continued)

A design refinement to single-wall construction consists of coloring the surface layers in high contrast to the inner layers, so that surface damage could be easily seen, signifying that a module should be replaced. Layer thicknesses should be designed to reveal superficial, surface damage before significant degradation of structural properties occurs.

The recommended development program for single wall laminated modules is to integrate appropriate interjoint sections, joints, and interjoint bearing connections into enclosure modules, and to perform cycling tests at the module level.

FABRIC MODULE CONSTRUCTION



LEG MOBILITY ISSUES

No compelling requirement for leg mobility was identified in the ECWS task requirements analysis, This raises the questions of whether to provide leg mobility or not, and, if so, under what circumstances.

The accompanying table summarizes the issues, and shows the following:

- Encasing the legs in a rigid "can" is an attractive concept for predictable, well defined EVA tasks, because it offers integration opportunities for work site hazards protection and LSS heat rejection.
- Leg mobility would be desirable in coping with emergencies or unforeseen situations.
- Leg mobility is essential for 1-g training.
- Crew acceptability of leg confinement requires assessment.

Issue	Pro	Con
Predictable construction tasks	-	Requires upper torso mobility only.
Vertical adjustment	Small range simple w/leg mobility.	Can be accomplished by adjusting workstand.
Unpredicted tasks and emergencies	Maximize crewman's capability	-
Crew acceptability	Leg mobility is known to be acceptable.	-
Leg enclosure construction	Soft legs feasible	Crotch life development required. Rigid "can" very rugged.
LSS Integration		Rigid "can" fosters: - Radiator integration - TDM in Base - Radiation protection - Transportation by crane/ cherry picker
1-g Training	Ability to walk is essential	

LEG MOBILITY RECOMMENDATION

The leg mobility recommendation is to expand the modularily concept of the EVA pressure enclosure to accept leg cans or flexible legs, as dictated by the mission or EVA sortie. Thus, for a 1-g training or for a particular crew of EVA workers in the vehicle, a few sets of flexible legs would be available. However, most EVA sorties may be conducted using the rigid leg cans.

Due to the unprecendented nature of rigid leg encasement, crew acceptability should be assessed prior to hardware design work.

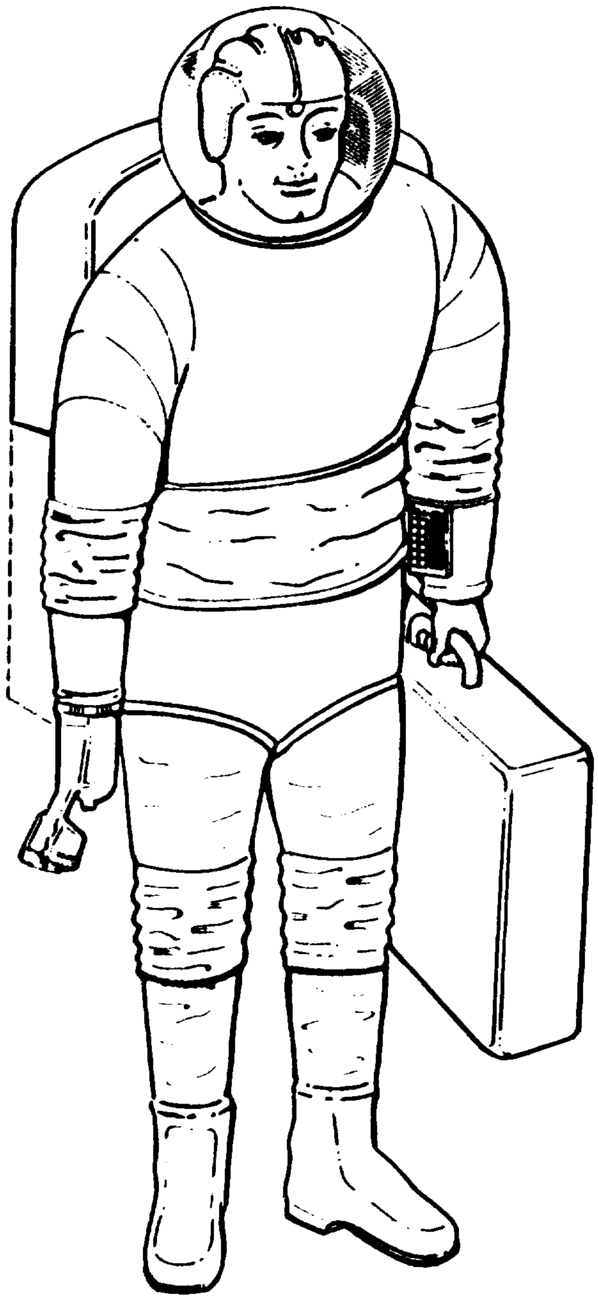
EVA PRESSURE ENCLOSURE DESIGN CONCEPT

The ECWS EVA enclosure design concept, resulting from the preceding recommendations, combines the best feature of the Shuttle EMU SSA and the NASA advanced technology suits to meet the requirements of the ECWS missions. As such the ECWS enclosure represents the coming together of two suit evolutionary lines, namely, the "soft" suit traditions of Gemini, Apollo and Shuttle programs and the "hard" tradition of the advanced technology NASA suits. In their present forms, both of these suit lines are hybrids, containing both hard and soft elements. The ECWS EVA pressure enclosure concept further blends the two traditions in areas that serve the particular requirements of ECWS missions.

The essential features of the ECWS EVA pressure enclosure are discussed as follows as they relate both to the ECWS requirements and to their origins in the "hard" or "soft" suit traditions.

Hybrid Suit - The hybrid suit in general, representing both hard and soft evolutionary lines, is well suited to the ECWS requirements. Most tasks are to be performed by one person, using hand-held tools, thus requiring an EVA crewman in an individual suit that has at least upper body mobility. The hybrid concept provides hard point LSS mounting with permanent, internal connections between the LSS and enclosure, which simplifies donning and doffing, and eliminates make-break vent loop connections or external vent loop hoses with their potential for leakage and for becoming snagged on worksite projections.

Modular Construction - Modular construction serves the ECWS requirements well in providing the on-orbit repair capability via replacement of individual damaged enclosure modular elements, such as joints or interjoint sections. This approach also saves vehicle stowage volume by not requiring the provisioning of large pressure enclosure subassemblies, such as whole limbs, that contain elements with a relatively low attrition rate. Replaceable modules already have been demonstrated in the advanced technology suits. Each module terminates in a metal ring bonded and flange-bolted to each end of the fabric elements. Intermodule connections are made via a slide wire retainer which locks one module termination within another in a plug-and-ring arrangement. The wire is installed with simple tools. An O-seal between the two module terminations seals the joint.



EVA PRESSURE ENCLOSURE DESIGN CONCEPT (Continued)

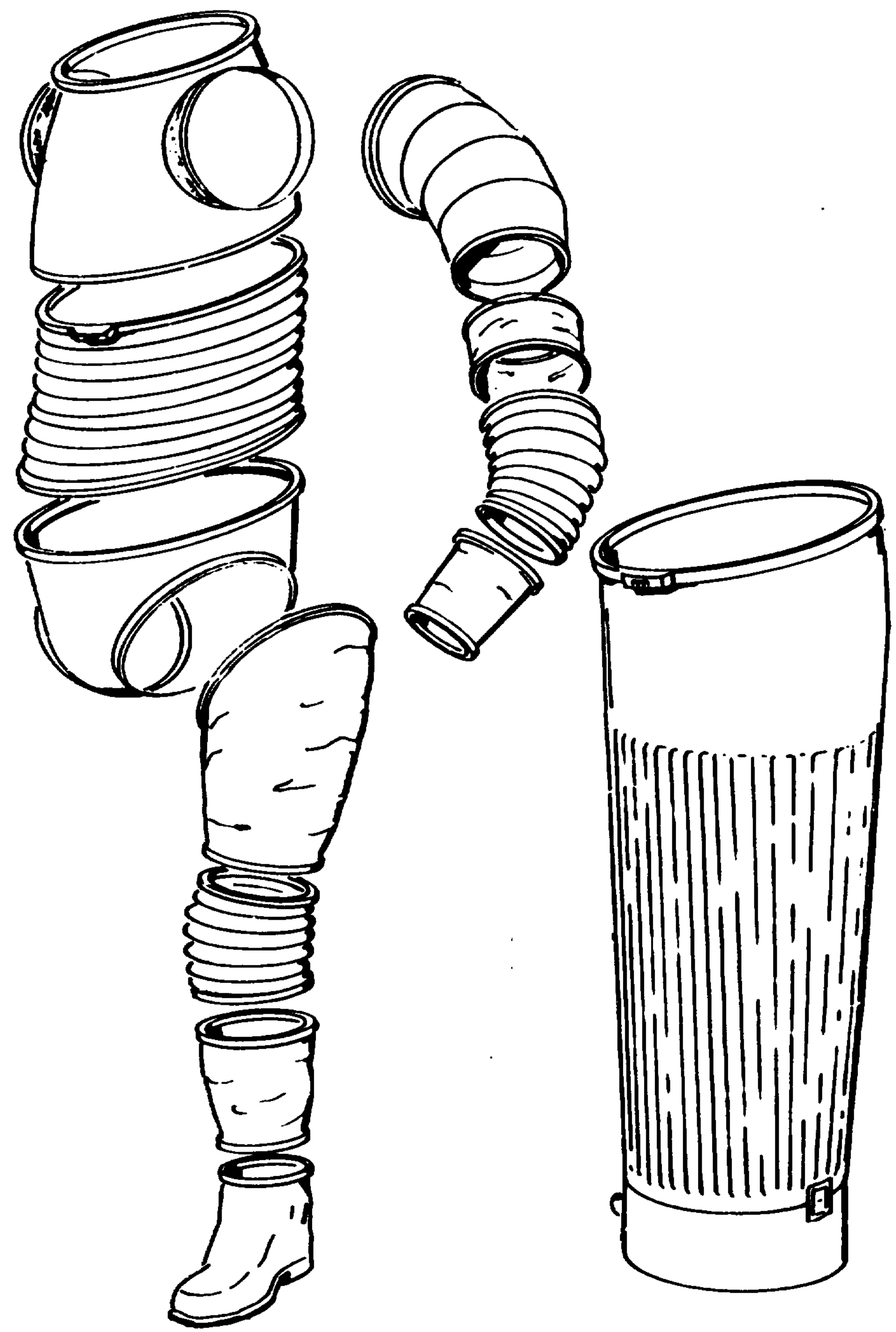
Full or Partial Mobility - Modular construction also fosters in-flight choice of full or partial mobility, depending on whether leg mobility is required for a particular EVA sortie or training run.

Sizing Modules - Sizing modules permit length adjustment by the addition of static modules between joints. Use of sizing modules is consistent with modular construction, because the sizing modules can become interjoint sections in the torso and limbs. Sizing elements permit progressive lengthening of the suit to accommodate spinal decompression in orbit, and thus help maintain suit comfort over the duration of the missions.

Single Wall Laminated Construction - Laminated fabric sections integrate the bladder and restraint layers into a single wall structure, and simplifies the termination of each module because the termination involves only one integrated fabric layer, not two separate layers. Its relatively firm, smooth inner surface promotes ease of donning and doffing, and is expected to be easily freshened and dried between EVA's to maintain acceptable hygiene. A design refinement consists of coloring the surface layers of a laminated structure in high contrast to the inner layers, so that surface damage is easily visible, signifying that a module should be replaced. Layer thicknesses would be designed to reveal superficial surface damage before significant structural properties degradation occurs.

LSS Interface - The LSS interfaces with the upper back portion of the EVA enclosure to keep the LSS close to the back when the crewman bends forward. This approach is common to both the EMU and advanced technology suits, and it is important that ECWS retain this feature to minimize on-the-back bulk and pass-through clearance requirements, and to maintain the ECWS center of gravity location within comfortable limits.

Bearings and Disconnects - Both the EMU and advanced technology suits use the same general types of bearings and disconnects. The bearings have integrated seals and ball spacers. These bearings, using forged steel races, are expected to be fully satisfactory for ECWS use. Disconnects have been demonstrated to be trouble-free in both suits and are expected to be satisfactory for ECWS use.



Boots - Boots of several standard external sizes will fit all projected foot restraint systems for ECWS. The boot itself will be a replaceable module, and will be fitted with an inner liner that is the sizing element to ensure conformance with the crewman's foot size. Molded ski boots with custom fit foam liners are an analogy.

LCVG - Both the advanced and Shuttle suits use the liquid cooling ventilation garment (LCVG) concept for cooling. This approach will be retained for ECWS, as it facilitates easy donning and doffing, provides adequate thermal control and, by incorporating the gas ventilation ducts as part of the LCVG, leaves the inner walls of the pressure vessel unencumbered with gas plumbing, which facilitates post - EVA drying and freshening. Several LCVG modifications are in order to meet unique ECWS requirements.

- A longitudinal growth capability should be provided to retain comfort as the crewmen grow in length during the mission, as well as to fine-tune the fit to individual preferences.

- The chiffon liner should be concepted as a separate, elasticized body stocking to act as a sieve to retain shed hair, disquamitated skin and other body solids and oils close to the skin. This is expected to reduce the soiling of the LCVG, and hence should reduce the required LCVG laundering frequency. The chiffon liners will be like underwear, and will be designed for laundering after each use. This is an analogy with earth-based construction activity in that less-than-freshly laundered workshirts and trousers remain acceptable if an individual is able to bathe daily and don fresh underwear. It is expected that the liners may have relatively short lives, but since they will weigh very little (on the order of 5 oz), and will occupy very little storage volume (on the order of 10-20 in^3), it is feasible to consider that their useful life can be significantly less than one 180-day mission.

Other Features

Other features of the ECWS EVA pressure enclosure such as the drink bag, waste management system, and IV umbilicals can l be similar to those being developed by the Shuttle EMU program.

HAZARDS PROTECTION

A rugged overgarment, exemplified by the thermal-meteroid garment (TMG) used by the Shuttle EMU, is a practical concept for the ECWS. This new overgarment will contain the requisite shielding for radiation protection and will also protect against puncture, tearing and abrasion at the worksite. The garment will also contain thermal insulation to protect against the extremes of heat and cold. A suggested acronym for this garment is THRO, for Thermal Hazards Radiation Overgarment. Like the laminated fabric structures of the EVA enclosure, the THRO should contain visible damage indicators to warn of superficial damage before its essential shielding functions are degraded.

Space construction represents the first EVA environment in which radiation protection considerations drive the design of EVA equipment elements. To achieve a practical, operational EVA construction capability will require the ability to perform daily EVA on a 180-day mission basis in all orbits contemplated for space construction, unrestricted by those periods when orbits pass through local regions of high radiation intensity, namely the polar horns and South Atlantic Anomaly (SAA).

By constrast the radiation protection afforded by the Shuttle EMU is adequate to support unrestricted EVA at the projected ECWS levels in only one of the proposed construction orbits, namely 28 1/2° inclination and 400 km altitude. For all other potential construction orbits of higher altitude or inclination the Shuttle EMU radiation protection is inadequate, and would require either increasing the radiation protection, or reducing the exposure to radiation during EVA by combination of some or all of the following EVA restrictions:

- Restricting EVA to occur only during the low radiation orbit segments.
- Reducing the EVA duration.
- Reducing the frequency of EVA sorties during a construction mission.

HAZARDS PROTECTION (Continued)

Notwithstanding the fact that the recent Space Station Systems Analysis Studies (SSSAS) define the 28 1/2° inclination orbit at 396 to 440 km altitude to be the "preferred construction orbit", the potential for EVA construction in higher radiation orbits must be acknowledged. Such construction would consist of fabrication of a solar power module, as well as construction activity associated with solar power satellite and communication antenna test articles. Specific indications of potential construction in other orbits are as follows:

- The Shuttle 576 flight model shows that 179 out of 382 EVA flights (47%) go to orbits of higher radiation than 28 1/2° 400 km.

- The SSSAS reports describe test articles to be built in LEO, but to be tested and evaluated in GEO. Therefore, potential exists for requiring GEO EVA for checkout, service and maintenance of these test articles.

THRO REQUIREMENTS

The following requirements define the basic performance and operating environments to guide the concepting of the ECWS THRO.

1. Heat Leak — +330 Btu/hr to -400 Btu/hr when used in conjunction with the EVA enclosure.

   These values are consistent with values currently established for the ECWS Study Program.

2. Workplace Hazards

   - Impact - The crewman shall escape impact injury resulting from a collision at 5 ft/sec of a crewman with a total of 1000 lbs, consisting of the crew man, the ECWS, personal propulsion and work materials.

   - Tearing - Pressure integrity shall be retained after drawing the EVA enclosure along an edge of TBD sharpness with a force of 45 lbs normal to the edge.

   - Puncture - EVA Pressure Enclosure integrity shall be retained after pressing the combined TMG - EVA enclosure against a point of TBD sharpness with a force of 25 lbs normal to the point.

   - Abrasion Resistance - Radiation and thermal properties shall not be degraded by TBD cycles of abrasion of the EVA enclosure across a surface of TBD roughness at a normal force of 45 lbs. The enclosure shall be designed to reveal abrasion damage visually before the thermal or structural properties are degraded.

   The above values are consistent with body force levels already established for projected ECWS tasks.

3. Ground Rules

- EVA Sortie Duration: 8 hours
- EVA Sortie Frequency: 6 Sorties per week
- Total Number of EVA Sorties: 154 Sorties per 180 day mission
- EVA Restrictions: No EVA during solar flare activity that has access to EVA orbit. Otherwise, EVA not restricted to low-exposure orbit segments.
- Contingency: Planned exposure is 60% of allowable 180-day dose, leaving 40% for unplanned exposure and contingencies.
- Transit to GEO: Round trip from LEO to GEO uses 10% of allowable 90-day exposure dose, leaving 90% of dose available for planned and unplanned GEO EVA.

Dose Limits

Radiation Exposure Limits, REM
Allowable (100%)

	90 Day	Yearly
Skin	105	225
Red BFO	35	75
Eye Lens	52	112

Exposure to 2 consecutive quarters is permissible provided that no further exposure causes exceedance of yearly limits.

Shielding Requirements

Orbit Inclination, °	28.5		55		0
Altitude, km	400	500	400	500	36K
Construction Base Vehicle Thickness Equivalent in. of Al	0.1	0.1	0.2	0.2	4.0
Orbital Transfer Vehicle Thickness	(For round trip using the 5 1/4 hr transfer)				0.5
EVA Shielding Requirements					
Skin dose limits, gm/cm^2					
Whole Body	0.1	0.3	0.5	0.7	-
Extremities only	-	-	-	-	1.2
Eyes and Red BFO limits, gm/cm^2					
Head and Torso only	-	-	-	-	2.0

4. Sizing

The following factors shall be considered relative to crewman comfort during repetitive long EVA use.

- Enclosure design shall consider sizing to fit a large segment of the 1985 population such as the 5th to 95 percentile male and female crew members and members of identified crews.

- On-Orbit Sizing shall include the provision for lengthening the torso to accommodate growth resulting from spinal decompression.

5. Mobility and Flexibility

The THRO shall not restrict or impair the motion ranges specified for the ECWS. Specified ECWS joint torque requirements shall be met with the THRO donned. The THRO shall be capable of being donned and doffed by the wearer, unassisted.

Requirements 3 through 5 are consistent with values previously established within the ECWS Study Program.

6. Other Requirements

Other requirements shall be consistent with the "Guidelines and Requirements Document" of the ECWS Study Program, contained in Section 4 of this volume.

THRO DESIGN CONCEPT

The requirements show that the amount of radiation shielding varies by a factor of 20 over the range of potential construction orbits. This fact suggests that the radiation shielding be divorced from the pressure enclosure, which is the most expensive part of the EVA enclosure, and makes it attractive to provide a variety of separate radiation-protective overgarments, each tailored to the severity of the radiation environment of a particular orbit. The following concept contains variable amounts of radiation protection integrated into a THRO. This concept also eliminates pressurizing the insulation, and having to flex additional inflated bulk.

Since the pressure enclosure, LCVG and LSS provide some measure of radiation protection themselves, the THRO must provide just the balance of the radiation shielding that comprises the total radiation protection requirement. The first of three accompanying tables show estimates of the radiation shielding inherent in the concept for the ECWS helmet, pressure enclosure and LSS described in this presentation.

The second table defines the amount of additional radiation shielding required to meet the total shielding defined in the requirements. The third table in this group completes the example by showing the weight of the additional THRO radiation shielding required by each part of the body as a function of the orbit. The following conclusions can be drawn from these tables.

- At 28 1/2° 400 km, no additional radiation shielding is required.
- At 28 1/2° 500 km, approximately 9 lbs of additional shielding is required over the torso front and side and extremities.
- At 55° approximately 17 to 25 lbs additional shielding are required over the entire body except for the back, depending on altitude.
- At GEO approximately 64 lbs of additional shielding is required over the entire body.

RADIATION SHIELDING PROPERTIES OF REPRESENTATIVE ECWS ELEMENTS

ECWS Element	Surface Density gm/cm^2	Surface Area ft^2	
Torso			
Soft Front and Sides	0.1	6.0	
hard Back (w/LSS)	0.4	3.0	
Arms and Hands (Gloves w/o LCVG)	0.1	5.8	
Flexible Legs and Feet (Boots w/o LCVG)		8.8	
		23.6 ft^2	TOTAL

ADDITIONAL THRO RADIATION SHIELDING REQUIRED TO MEET RADIATION ENVIRONMENTS IN EACH ORBIT, gm/cm^2

Orbit					
Inclination, °	28 1/2		55		0
Altitude, km	400	500	400	500	36K
Upper Torso					
Front and Sides	0	0.2	0.4	0.6	1.9
Rear	0	0	0	0	1.3
Arms and Hands	0	0.2	0.4	0.6	1.1
Legs and Feet	0	0.2	0.4	0.6	1.1

WEIGHT ESTIMATES OF THRO RADIATION SHIELDING

Region of Body	ORBIT 28 1/2° 400	28 1/2° 500	55 400	55 500	0 36K
Torso					
Front and Sides	0	1.6	3.6	6.1	22.0
Back	0	0	0	0	8.0
Arms and Hands	0	2.4	4.8	7.1	13.0
Flexible Legs and Feet	0	3.6	7.2	10.8	19.8
TOTAL	0	7.6	15.6	24.0	62.8

THRO CANDIDATE MATERIALS

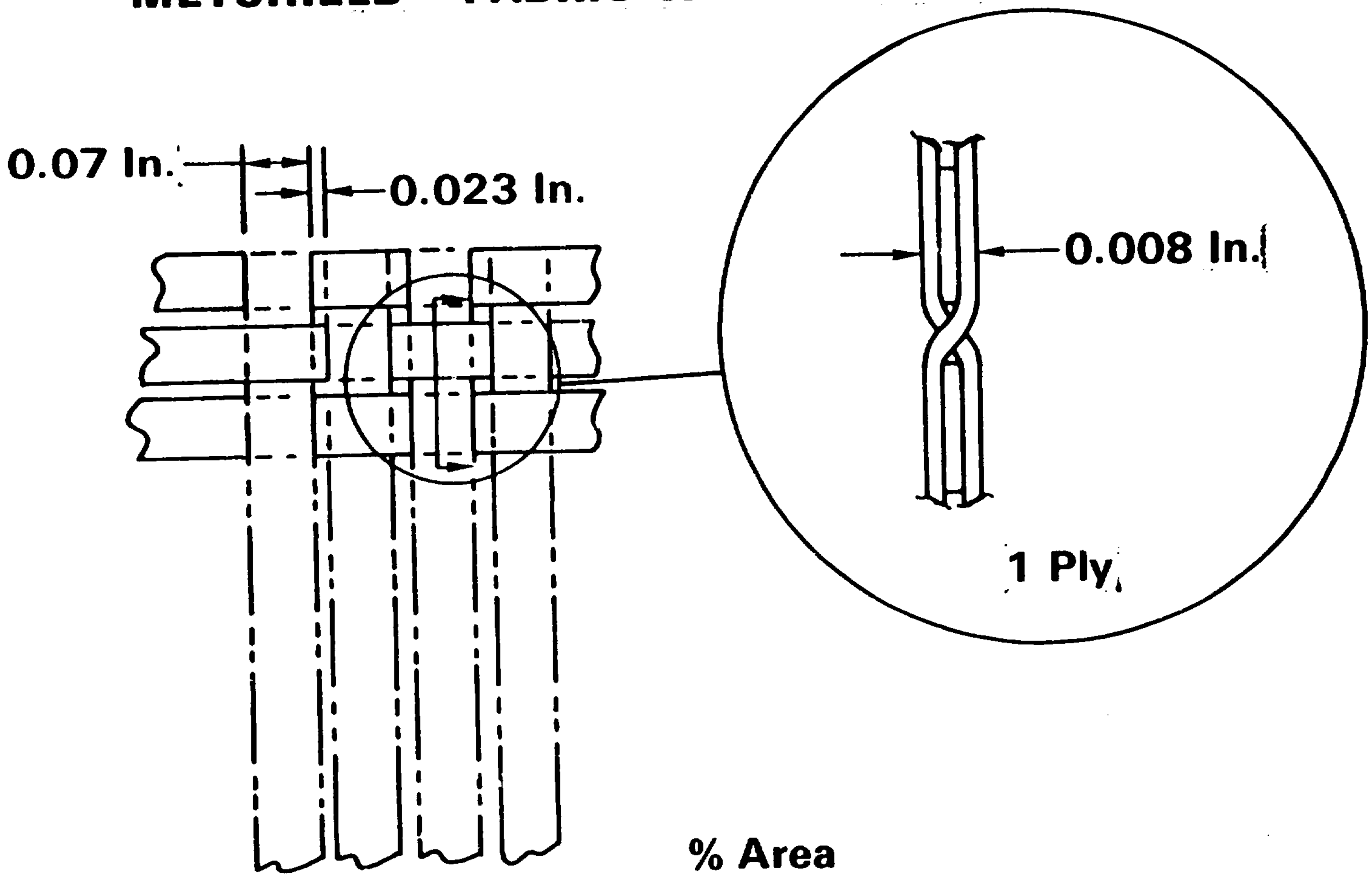
Several candidate materials were evaluated in order to determine if sufficient material for shielding retained adequate flexibility for use in a practical THRO.

Material and Manufacturer	Characteristics	Thickness and Surface Density
- Lead Foil Common Commercial Product	Judged very flexible. Has high hysteresis and low fatigue cycle life. Not recommended for joint areas.	0.002 in. 0.0578 gm/cm^2
- Multidrawn Chromel-R Fabric Prodesco Inc. Perkasie, PA or Fabrics Research Laboratories, Inc. Dedham, Massachusetts	Multidrawn metal fabric woven of yarn comprised primarily Ni, with a lesser amount of Cr, plus minor percentages of Fe, Al, Si, Mg, Sb and C. Yarn has 100 1/2 mil filaments. Fabric is a 2 x 2 twill with 60 + 2 warp and 70 + 2 fill count. Fabric exhibits cloth-like flexibility. Prime candidate for joint areas.	0.011-0.012 in 0.055-0.077 gm/cm^2
- Lamipore W. L. Gore, Assoc. Elkton, Maryland	80% Pb powder suspended in porous web of 20% TFE. Developed as flexible radiation shielding for garments. Pime Candidate for general use in all joint and non-joint areas.	0.010 in. 0.1651 gm/cm^2

THRO CANDIDATE MATERIALS (Continued)

Material and Manufacturer	Characteristics	Thickness and Surface Density
- Metshield™ Fabric Allied Allied Chemical, Metglas Products Florham Park, New Jersey	Metallic Glass, consisting of non-crystalline alloy of Fe, Ni, P and B is formed by cooling liquid melt at rates in excess of 10^6°F/sec. Non-crystalline amorphous structure reduces stiffness. Fabric is woven of ribbon 0.07 wide x 0.002 thick. Refer to accompanying Figure. Open weave suggests use in multi-ply applications only. Material is extremely tough. Not recommended for joint areas requiring high flexion in 3 dimensions.	0.008 in. 0.0651 gm/cm^2
- Lead In Metshield Form Not currently in production.	A reference material proposed to facilitate comparison with Metshield alloy. Geometry of accompanying Figure applies.	0.008 in. 0.089 gm/cm^2

METSHIELD™ FABRIC WEAVE CHARACTERISTICS



% Area

No. of Plies	4 Layer	3	2	1	Open
1 Ply	—	—	56.6	37.2	6.1
2 Ply	32.0	42.1	20.7	4.5	0.4

Tough Material — Recommended for Interjoint Areas

5-187

THICKNESS AND NUMBER OF PLIES REQUIRED OF CANDIDATE
RADIATION SHIELDING MATERIALS

Shielding Material	Shielding Requirement, gm/cm²							
	0.1	0.5	0.4	0.6	1.1	1.3	1.6	1.9
	Number of Plies/Thickness							
Metshield™ (0.008 in.)	2/.016	3/.024	6/.048	9/.072	17/.136	20/.016	25/.02	29/.232
Lead Foil (0.002 in.)	2/.004	4/.008	7/.014	10/.020	19/.038	23/.046	28/.056	33/.066
Multidrawn Chromel-R Fabric (0.002 in)	2/.024	3/.036	6/.072	9/.108	16/.192	20/.240	23/.276	29/.348
Lead Foil (0.002 in.)	2/.004	4/.008	7/.014	10/.020	19/.038	23/.046	28/.056	33/.066
Lamipore (0.010 in.)	1/.01	2/.02	3/.03	4/.04	7/.07	8/.08	10/.10	12/.12

THICKNESS AND NUMBER OF PLIES REQUIRED OF CANDIDATE RADIATION SHIELDING MATERIALS (Continued)

The above requirements appear to be implementable in a practical THRO. The actual THRO would probably combine different materials as follows:

- Outer layers - tough, lower density to provide puncture, tearing and abrasion resistance and to attenuate radiation while minimizing production of secondary X-rays.

- Inner layers - high density to further attenuate radiation and absorb the secondary X-rays.

- Construction would range from 1 to 33 layers yielding thicknesses from .004 to .348 inches.

HELMET

As with other parts of the ECWS EVA enclosure, a practical space construction capability imposes several requirements on the helmet not required of the Shuttle EMU. These consist of "hands-off", integrated visoring, wide angle vision, additional radiation protection and manufacturing economy.

Sixty minutes out of every 96 minute orbit are spent with the space station in the Sun. During this time construction activity will take place in the full spectrum of lighting conditions from full sunlight to full Earth shadow with all levels in between being provided by reflection from the space station and the structure under construction. As the crewman moves from place to place, or even turns around, his eyes will encounter large, abrupt changes in light levels.

To compensate for the abrupt variation in light levels reaching the eye, the crewman will require rapidly adjustable helmet visoring. Using the present Shuttle EMU EVVA the crewman must make these adjustments manually. However, this could be inconvenient or impossible if both hands were full, performing EVA tasks. (Imagine the problem of being suddenly blinded by full sunlight during the final berthing of multi-thousand lb payload or structure subassembly.) Thus, visoring that responds automatically to changes in light intensity would keep the crewman's hands free to perform the intended EVA work safely and comfortably.

Recent underwater construction simulation testing at MSFC has revealed the desirability of having a field of vision greater than the 185° temporal field provided by the Shuttle EMU helmet and EVVA to improve the ability to communicate and to handle long structural elements. The ECWS helmet should eliminate the constraints on the field of vision, as imposed by mechanical visor elements, and make possible a wide angle field of view, limited only by the ability of the crewman to rotate his head and eyes, and not be limited by the helmet and visor at all.

The requirements for repetitive, daily EVA make it desirable to simplify the donning and doffing of the ECWS. To this end an integrated visor and helmet concept will eliminate the requirement to don, doff and stow the separate EMU EVVA, as presently required by the Shuttle EMU.

HELMET (Continued)

Helmet fabrication techniques and materials bear investigation because the results may indicate functional and economic advantages of changing the present EMU helmet design and manufacturing process. The present manufacturing process for Shuttle EMU helmets uses press-polished polycarbonate sheets which are blow molded into a female mold. The resulting helmet is well suited to space flight because it is lightweight, reliable, adaptable to sun visors, and it provides adequate visual range for Shuttle EVA. However, the present inspection process is highly critical in several respects causing a high helmet rejection rate, and thus causes the helmets to be expensive. In addition, the relatively flat sides of the helmet design present minimum donning clearance with respect to the head.

HELMET REQUIREMENTS

The following requirements define the basic performance and operating environments to guide the concepting of the ECWS helmet.

1. General

   The ECWS helmet shall be an integrated helmet and visor assembly. Visor actuation shall be automatic, in response to ambient light levels.

2. Field of Vision

   The field of vision shall be as follows:

   - Upward 120°
   - Side to Side ±120°
   - Downward 70°

   These values correspond approximately to the range of head and eye motions, considering the shoulders to be fixed. Thus the specified field of vision is defined by the human anatomy, and is not limited by the helmet or its visors.

3. Optical Properties

   The optical properties of the helmet and visor shall be as follows:

		Visor "Open"	Visor "Closed"
Transmissibility at	550 nm wavelength	80%	7%
	1100 nm	-	10%
Solar Reflectance	550 nm	70%	83%
Back Reflectance	550 nm	8%	13%
Haze		2% max	
Refraction in any meridian		±0.06 diopters	

Color	Equal to that which is inherent in clear, untinted, unstabilized polycarbonate material.
Coatings	The helmet shall incorporate an anti-abrasive coating on the outside and an anti-fogging coating on the inside.

These values and requirements are consistent with the optical properties of the Shuttle EMU helmet and EVVA.

4. Cycle Life

The neck ring disconnect shall have a cycle life of 2,000 installation-removal cycles. This is consistent with:

$$10 \text{ missions} \times 154 \; \frac{\text{EVA's}}{\text{Mission}} \times 1 \; \frac{\text{Cycle}}{\text{EVA}} = 1{,}540 \text{ cycles}$$

The visor shall have a cycle life of 2×10^6 maximum transparency to maximum opacity cycles. This is consistent with:

$$10 \text{ missions} \times 154 \; \frac{\text{EVA's}}{\text{Mission}} \times \frac{8 \text{ hr}}{\text{EVA}} \times \frac{60 \text{ min}}{\text{Hr}} \times \frac{1}{96} \frac{\text{Orbits}}{\text{Min}} \times \frac{60 \text{ Mins of Sunlight}}{\text{Orbit}}$$

$$\times \frac{4 \text{ Cycles}}{\text{Min of Sunlight}} = 1.848 \times 10^6 \text{ cycles}$$

5. Total Life

Total life shall be 90,000 hours, which is consisten with the 10 year useful life expectancy requirement of the ECWS.

$$10 \text{ years} \times \frac{365 \text{ days}}{\text{year}} \times \frac{24 \text{ hr}}{\text{day}} = 87{,}600 \text{ hours.}$$

6. Radiation Protection

The helmet shall provide radiation shielding as follows as a minimum.

Orbit Inclination, °	28 1/2		55		0
Orbit Altitude, km	400	500	400	500	36K
Shielding, gm/cm^2	0.1	0.3	0.5	0.7	2.0

7. Leakage

The helmet leakage shall be less than 8.0 scc of O_2 at an internal pressure of 4.0 psig. This is the same as the leakage value for the Shuttle EMU helmet during ground testing.

8. Pressure Requirements

Nominal Operating Pressure shall be 8 psid.

Proof Pressure shall be 16 psid.

Ultimate Pressure shall be 20 psid.

These values are consisten with potential ECWS operating pressure levels up to 8.0 psia.

9. Impact Resistance

The helmet shall have an impact resistance of 100 foot-pounds to an object with a 1-inch radius point. Effective mass of the object shall be 12.4 slugs. These values are consistent with those for the Shuttle EMU.

10. Other Requirements

Other requirements shall be consistent with the "Guidelines and Requirements Document" of the ECWS Study Program, in Section 4 of this volume.

HELMET DESIGN CONCEPT

The ECWS helmet concepted to meet the above requirements is shown in the accompanying illustration. It consists of a single assembly composed of a clear, outer, polycarbonate plastic bubble secured to the EVA enclosure by a neck ring disconnect. This bubble provides the helmet structural integrity and pressure retention. The liquid crystal visoring panels, forming four vision zones, are bonded to the inside surface of the bubble like tiles. A miniature photo sensor, located in the middle of each visor panel, senses the intensity of ambient light falling on each visor panel, and causes an electronic control, located in the back of the helmet, to regulate the transmissibility of the visor panel accordingly.

Optical Properties

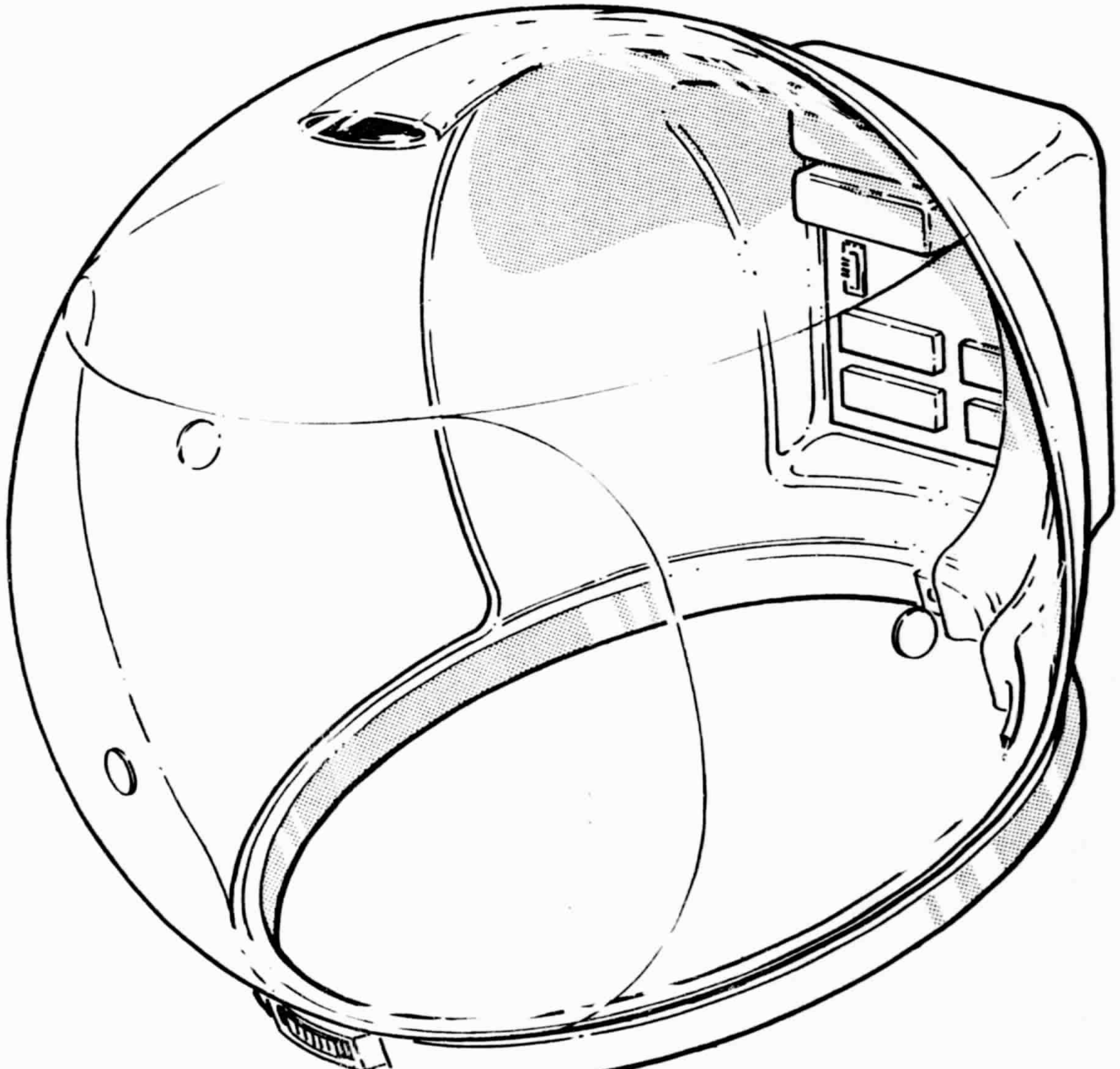
The optical properties requirements are designed to protect the eyes as follows:

- Ultra violet (up to 400 nm) - To protect the cornea from damage.
- Visible light (400 - 700 nm) - To protect the crewman from the discomfort of too-bright light, yet to permit vision in low light.
- Infrared (700 to 2400 nm) - To protect the retina from damage.

Clear, uv-stabilized polycarbonate plastic, as specified for the outer bubble, provides adequate uv protection. This is the approach used for the Shuttle EMU helmet and EVVA, and needs no further refinement for the ECWS.

Visible light protection will be provided by the liquid crystal panels. The panels will cover 4 viewing zones - frontal, temporal (2 sides) and superior (upper). Transmissibility of each panel will be individually and automatically adjusted by a miniature, solid state electronic controller responding to a sensor input from a photocell mounted in the center of each panel.

Liquid crystals of the field-effect type appear to be well suited to perform the visoring task. They have been continuously and significantly improved since their introduction in the early 1970's, and are currently being marketed as both digital output displays and as "light valves". It is this latter use that is of interest as an EVA helmet visor.



HELMET DESIGN CONCEPT (Continued)

Typical liquid crystal displays or light valves consist of two parallel glass plates separated by 0.5 mils. The space in between is filled with the liquid crystal material. Continuous, transparent electrodes are plated on the inner surfaces of both glass plates. Wires to the electronic controller are connected to the electrodes on the inner plate. When a voltage is applied between the electrodes, the plane of polarization is rotated, transmitting light from the outside through the material, rather than reflecting the light back.

The voltage is typically ac at 25 to 1000 Hz and 3 to 15 volts. Power requirements are very low. Typical displays using liquid crystals consume micro watts (10^{-6}) or nano-watts (10^{-9}). The low power consumption should allow the helmet electronic controller to be battery powered, and thus eliminate any electrical connections between the EVA enclosure and helmet.

Liquid crystals operate over a temperature range of -5°C (17.6°F) to +80°C (176°F). The active temperature control within the helmet, required for life support, would be expected to keep the liquid crystal temperature well within this range.

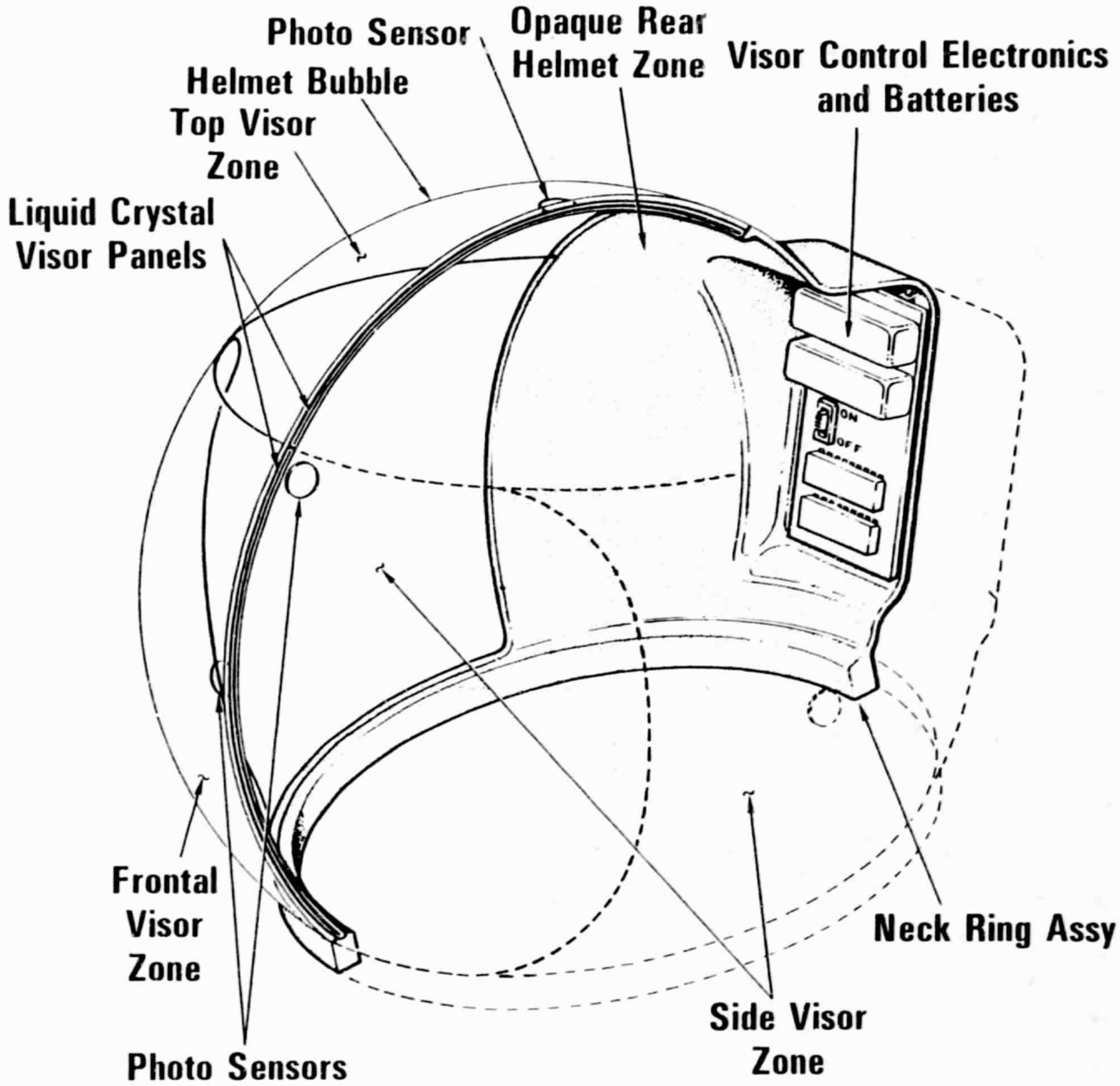
Transient times of liquid crystals are constantly being improved. Current values are:

	75°C	0°C
Turn-on (become opaque)	75 ms	150 ms
Turn-off (becomes transparent)	150 ms	600 ms

Technology development is required to shorten the response time, so that 10-15 complete turn-on/turn-off cycles could be completed per second. This would permit variation of transmissibility without visible flickering, and would make possible a continuously variable degree of transmissibility by pulse-width modulation of the electronic controller output.

Additional technological developments include fine tuning the required range of opacity and transparency. Current field-effect liquid crystals are available providing a 15% to 85% transparenty range (approximately a 5.6 to 1 ratio). The requirements for visoring are 7% to 80% (11.5 to 1). Present state-of-the-art liquid crystals will provide a 15 or 20 to 1 ratio. In addition, 10 year ECWS life requires a 90,000 hour total life. Current liquid crystal useful lives of 50,000 hours are now being quoted, but this will require improvement. Lastly, fabrication of spherical panels would be required. Current technology is for flat panel construction.

HELMET DESIGN CONCEPT



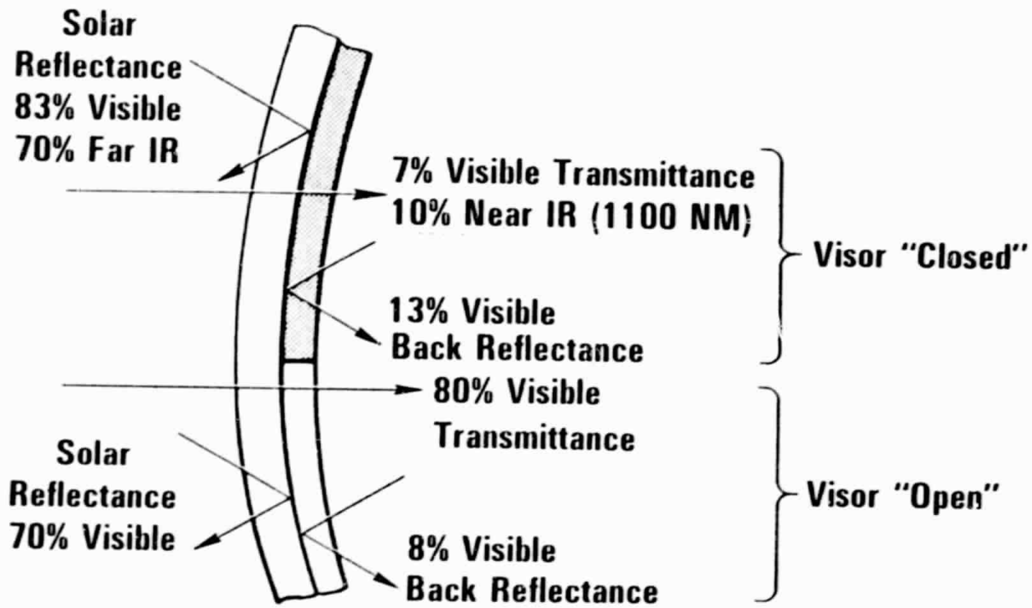
HELMET DESIGN CONCEPT (Continued)

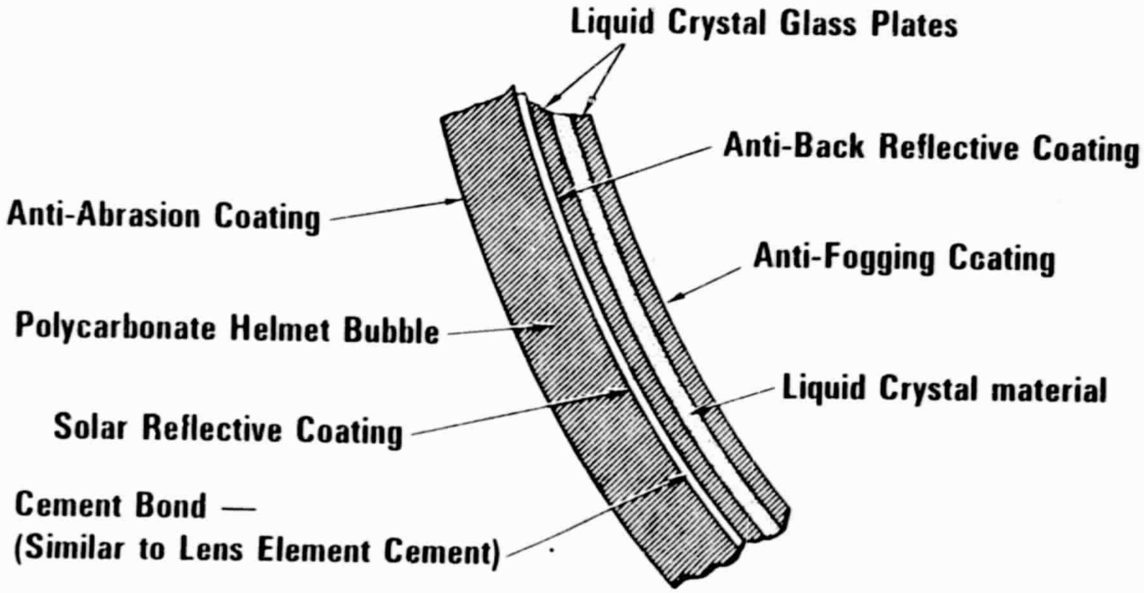
Liquid crystals appear to be safe for use. The materials are non toxic (in case of breakage), and the field-effect crystals become opaque with loss of voltage, thus failing closed with loss of controller function.

IR protection will also be provided by the liquid crystal visor panels. Fine tuning of the transmissibility and reflectance of both IR and visible light can be supplemented by use of an additional solar reflectance coating applied to the inner surface of the polycarbonate bubble. A coating such as Perkin-Elmer LEV-20, with 70% visible light transmittance and 90% IR reflectance, depending on thickness, should be useful for this purpose.

Optical properties will be preserved by using an anti-abrasive coating, such as Dow Corning ARC, currently used on the Shuttle EMU Helmet, applied to the outer surface of the polycarbonate bubble. An additional coating to control internal light reflection and minimize IR heat loss, such as Perkin-Elmer LR, will be applied to the outer surface of the liquid crystal visor panels prior to bonding the panels to the helmet bubble. An anti-fogging coating, such as the tricresylphosphate coating developed for Apollo, will be applied to the inner surface of the liquid crystal visor panels. Integration of the coatings, visor panels, and the helmet bubble is shown in the accompanying illustration.

OPTICAL PROPERTIES AND INTEGRATION





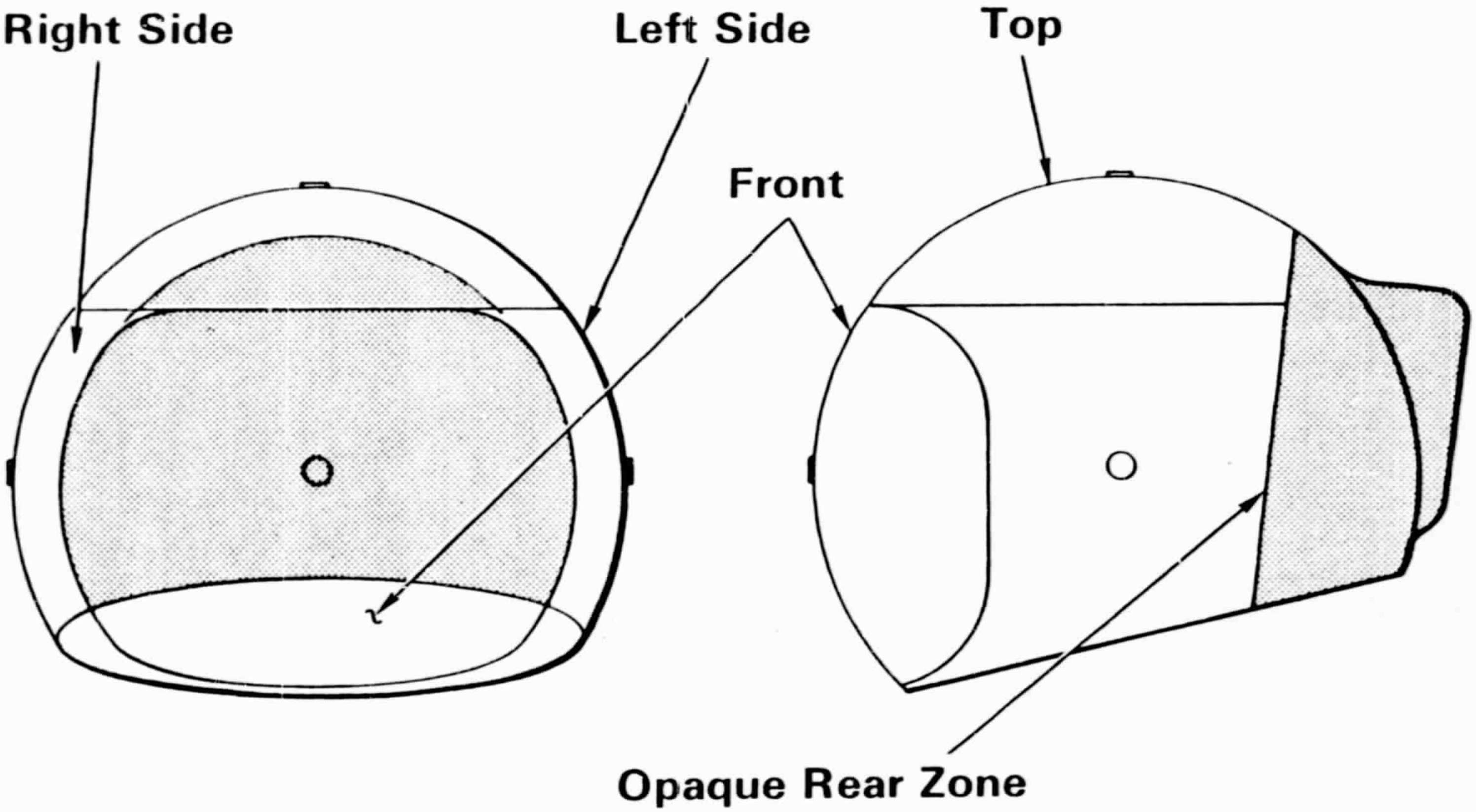
Zoning and Control

To provide the wide angle of vision, and yet to visor that portion of the head facing towards the sun and to leave unvisored that portion of the head facing away from the sun, requires dividing the visual field of the helmet into zones as shown in the accompanying illustration. The entire helmet that is within the view field is divided into 4 visor zones, a frontal, top, and two side zones. The back of the helmet, which is out of the view field, is permanently opaque and contains provisions for mounting the visor electronic controller.

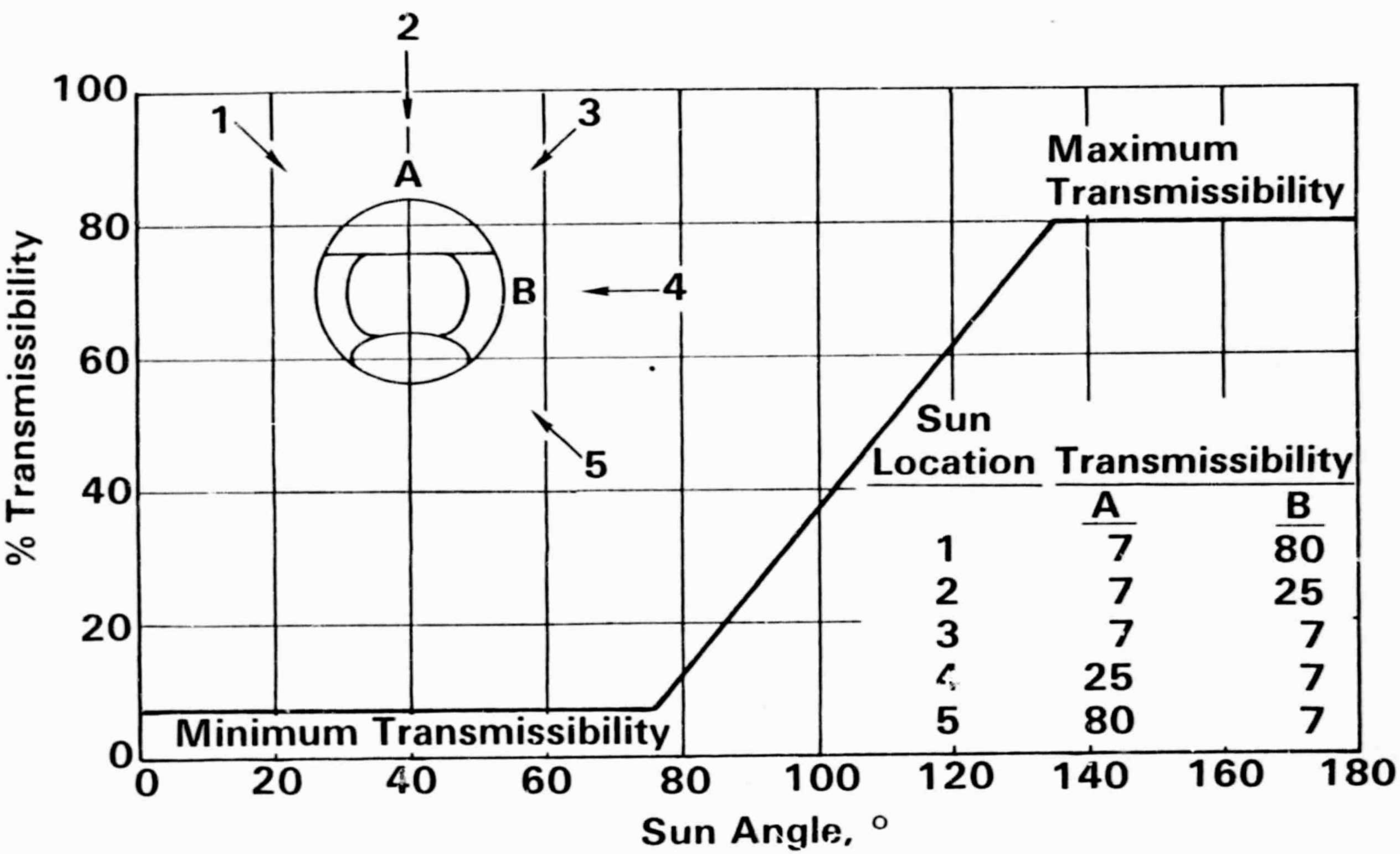
The four view-field zones will be controlled individually by one sensor in each zone. The controller will drive the transmissibility to the schedule shown in the accompanying schedule. A visor panel facing the sun has minimum transmissibility and remains so until the sun angle is approximately 75° off-axis. A panel at 90° to the sun has 25% transmissibility and achieves maximum transmissibility for sun angles of 135° and greater.

The zoning and control thus provided allows fully "hands off" visoring over the entire wide angle view, and allows variable visoring for those sun angles critical for comfort where the sun just passes into or out of direct view. The zoning also allows the visors to operate as required to compensate for strong surface reflections.

HELMET ZONES



LIQUID CRYSTAL VISOR CONTROL SCHEDULE



HELMET DESIGN CONCEPT (Continued)

Radiation Protection

The present Shuttle EMU helmet construction provides 0.4 gm/cm^2 radiation shielding. Therefore, the amount of additional shielding to meet LEO and GEO requirements is as follows:

	28 1/2		55		0
	400	500	400	500	36K
Total Shielding Requirement, gm/cm^2	0.1	0.3	0.5	0.7	2.0
Present EVA Helmet, gm/cm^2	0.4	0.4	0.4	0.4	0.4
Additional Shield Requirement, gm/cm^2	0	0	0.1	0.3	1.6

As can be seen, little additional shielding is required for LEO work. A 5-fold increase is needed for GEO, which does not appear to be unsurmountable.

Glass and plastic, as represented by Lexan polycarbonate, are candidate materials. Total weight and thickness of these materials to produce helmets with more shielding than the EMU helmets, based on 2.2 ft^2 of helmet surface, are as follows:

	Total Shielding Requirement		
	0.5 gm/cm^2	0.7	2.0
Lexan, Sp. gr. 1.2	.16 in. thick 2.2	.23 3.2	.66 9.1
Glass, Sp. gr. 3.6	-	-	.22 9.1

From the above it appears that helmets of practical weight are feasible. Since the weight difference between the two LEO helmets is small, use of the 0.7 gm/cm^2 version is suggested for all LEO work.

EVA GLOVES

EVA gloves are the active interface between the EVA crewman and the work being performed. All manipulative tasks performed with body forces and motions are performed through the gloves, and the tactile sensation used to control the motions are fed back through the gloves. Accordingly, EVA gloves must provide a proper balance of mobility, tactility, comfort and protection from workplace hazards to support the particular requirements of EVA work.

Present NASA EVA glove designs were not designed for heavy work, such as EVA construction, but rather were designed to meet payload support requirements or to demonstrate the particular design features required to meet 8 psig or 14.7 psig operation. They feature good comfort and mobility, but are either too light to support EVA construction work or are too bulky to permit comfortable, long term use of hand tools.

The design challenge of EVA gloves is to combine comfortable use with protection from workplace hazards, while performing the full range of EVA tasks. The EVA tasks are as follows:

- Position payload construction materials, and install and remove construction equipment.

- Perform construction, consisting of fabricating structural elements from rolls or coils of stock launched from earth, assembling and installing structural elements and other subassemblies and modules, or deploying folded structure subassemblies launched from earth.

- Perform alignment, checkout and activation.

- Perform maintenance, repair and replenishment of expendables.

- Use and evaluate the payload or structure for its intended purpose.

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- Use and evaluate the payload or structure for its intended purpose.

Manual tasks associated with the EVA activity will include:

- Using tools for cutting, trimming and making holes.

EVA GLOVES (Continued)

- Using tools for mechanical assembly, welding or fuse bonding.
- Using tools and special equipment for aligning and for checking out subsystems.
- Using supplies for cleaning and servicing.
- Manually opening payload access panels and/or operating payload controls.

EVA GLOVE REQUIREMENTS

The following requirements define the basic performance and operating requirements to guide the concepting of EVA gloves.

1. General

EVA gloves shall protect the crewman's hands during EVA, retaining suit pressure, while permitting the crewman to perform all manual EVA tasks. The gloves shall flex in a natural manner.

2. Hand Motions

The EVA glove shall permit hand motions typified by the following:

- Finger twirling as required to engage mechanical fasteners and turn finger-tight. Minimum object diameter is expected to be 0.5 inch.
- Finger-palm grip and wrist rotation, as required to tighten a fastener with a screwdriver. Minimum tool handle diameter is expected to be 1.0 inch.
- Palm grip with forearm rotation, as required to torque a fastener with a ratchet wrench.
- Delicate grip with thumb and index finger, as required to position a wiring harness.
- Moderate grip with thumb and all fingers, as required to grasp solid objects such as wave guides.
- Hard grip with thumb and all fingers against the palm, as required to turn a turnbuckle or crank.
- Outstretched palm and fingers are required to push a large object away.

EVA GLOVES REQUIREMENTS (Continued)

3. Mobility

The following specific motions shall be required:

	Range	Torque (ft. lb)
Wrist - flexion, extension, abduction	$\pm 60°$	0.5
adduction	$\mp 30°$	0.5
Fingers - first metacarpal flexion	90°	0.1
Thumb - first metacarpal flexion, extension	$\pm 30°$	0.1

Thumb and fingers shall be capable of opposition. Other finger and thumb joints shall be capable of flexion to complete the grasp of a 0.5 inch diameter object.

4. Cycle Life

The EVA glove shall have a cycle life of 500,000 joint cycles. This is consistent with the requirements for one 180-day mission, with EVA usage as follows:

$$\frac{6 \text{ joint cycles}}{\text{Min}} \times \frac{60 \text{ min}}{\text{Hr}} \times \frac{8 \text{ hour}}{\text{EVA Sortie}} \times 154 \frac{\text{EVA Sorties}}{\text{180 day Mission}} = 433{,}520 \frac{\text{cycles}}{\text{mission}}$$

5. Temperature Environment

-180°F to +200°F at an application pressure of 2.0 psi for two minutes. Occasionally there will be a requirement to handle objects as hot as 450°F.

6. Leakage

The glove leakage shall not exceed 5 scc/min at 4 psig.

EVA GLOVES REQUIREMENTS (Continued)

7. Pressure Level

Mobility requirements shall be met at 8.0 psig.

8. Radiation Protection

The EVA glove shall meet the following schedule of radiation shielding requirements:

Orbit Inclination; °	28 1/2		55		0
Altitude, Km	400	500	400	500	36K
Shield requirements gm/cm^2	0.1	0.3	0.5	0.7	1.2

9. Sizing

The following factors shall be considered relative to crewman comfort during repetitive, long EVA use.

- Glove and human joint centers shall coincide.
- The EVA glove shall be free of pressure points and chafe areas.
- EVA glove design shall consider sizing to fit a large segment of the population, for example 5th to 95 percentile male and female crew members in the 1985 time frame.
- On-orbit sizing shall include the provision for changing the wrist-to-palm segment length to accommodate changes in arm and shoulder fit.

Requirements 4 through 9 are consistent values previously established within the ECWS Study Program.

EVA GLOVES REQUIREMENTS (Continued)

10. Workplace Hazards

The EVA glove shall protect the EVA crewman against the following workplace hazards.

- Cutting - Pressure integrity shall be retained after drawing the EVA glove along an edge of TBD sharpness with a force of 45 lbs normal to the edge.

- Puncture - Pressure integrity shall be retained after pressing the EVA glove against a point of TBD sharpness with a force of 25 lbs normal to the point.

- Abrasion Resistance - Pressure integrity and thermal properties shall not be degraded by TBD cycles of abrasion of the EVA glove across a surface of TBD roughness at a normal force of 45 lbs. The glove shall be designed to reveal abrasion damage visually before structural properties are degraded.

The above values are consistent with body force levels already established for projected ECWS tasks.

11. Wrist Disconnect

The EVA glove shall be connected to the EVA enclosure forearm via a quick disconnect of the type used in the Shuttle EMU.

12. Other Requirements

Other requirements shall be consistent with the "Guidelines and Requirements Document" of the ECWS Study Program in Section 4 of Volume.

ECWS GLOVE CONCEPT

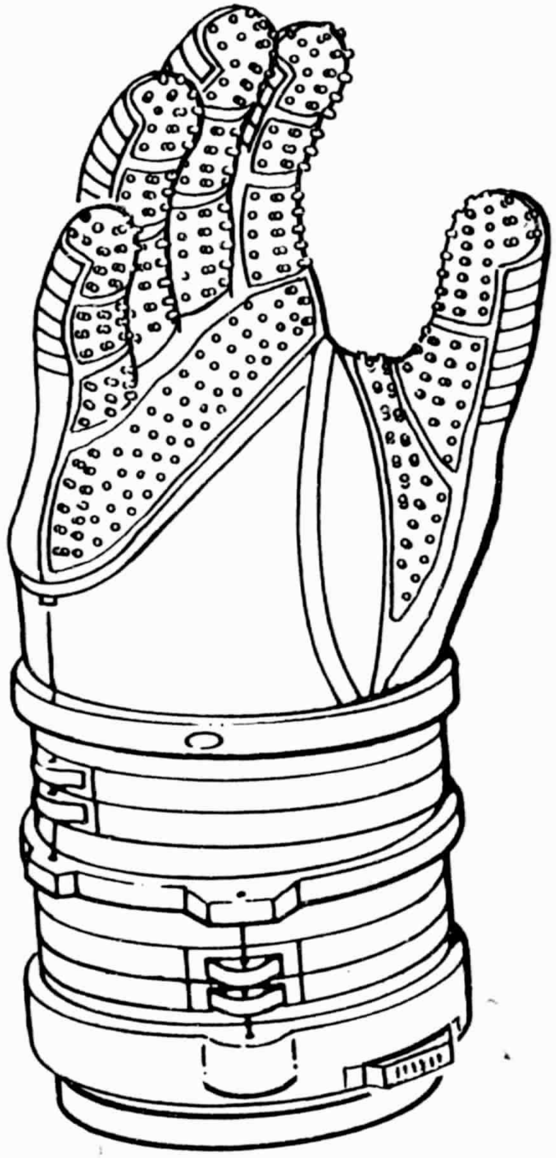
The ECWS EVA glove concept relies heavily on the best features of existing NASA EVA glove designs, as well as adding some new features to make it suitable for EVA construction use. In general the ECWS EVA glove concept consists of a modular, molded, single wall laminated glove structure that integrates the pressure retention bladder and the restraint layers into a single wall construction. Thermal insulatipn to accommodate work piece surface touch temperature extremes of -180°F to +200°F is included in the basic glove. Solar radiation protection is provided by cover layers that are tailored to the particular construction EVA orbit. The general features of the ECWS EVA glove concept are shown in the accompanying illustration.

The glove, as concepted, interfaces with the EVA enclosure via the present Shuttle EMU wrist disconnect. The disconnect mounts to a wrist module sizing element designed to make the center of wrist flexure coincide with the crewman's wrist. The second modular section is the wrist joint itself. This is consistent with the modular construction of the rest of the EVA enclosure, in which major joints and sizing elements are separate modules. A two-axis flat pattern joint is a likely candidate for the wrist joint, as this joint concept appears capable of being developed for 500,000 cycle life, which is one ECWS mission.

The palm and fingers comprise the third and last module of the EVA glove concept. The concept of modularity appears to be particularly appropriate to the EVA glove, because wear and tear of the workplace, as discussed in more detail later in this section, may well require some of the finger and palm modules to be replaced during the course of an ECWS mission.

The palm configuration features minimum rigid bulk to facilitate the finger-palm grip required for comfortable gripping and turning tools.

The fingers and thumb are also concepted to be of molded, single wall, laminated construction. A leading contender for the first metacarpal joint of the thumb and fingers is the rolling convolute joint, which has exhibited high comfort and mobility at 8 psig in existing NASA gloves, and which appears capable of being developed for 500,000 cycle life. A likely contender for the other metacarpal joints is the mini-convolute concept in which bellows-like convolutions are molded into the back side of the knuckles to permit flexion of the fingers.



ECWS GLOVE CONCEPT (Continued)

Except for palm design, the existing NASA glove designs provide a sound technological basis for achieving life, mobility, tactility and comfort required of ECWS. However, the areas of thermal protection, solar radiation and workplace hazards protection require the ECWS EVA glove concept to break new ground.

Thermal Protection

Thermal protection presents some EVA glove design problems that require different solutions from those that use conventional super insulation, specifically:

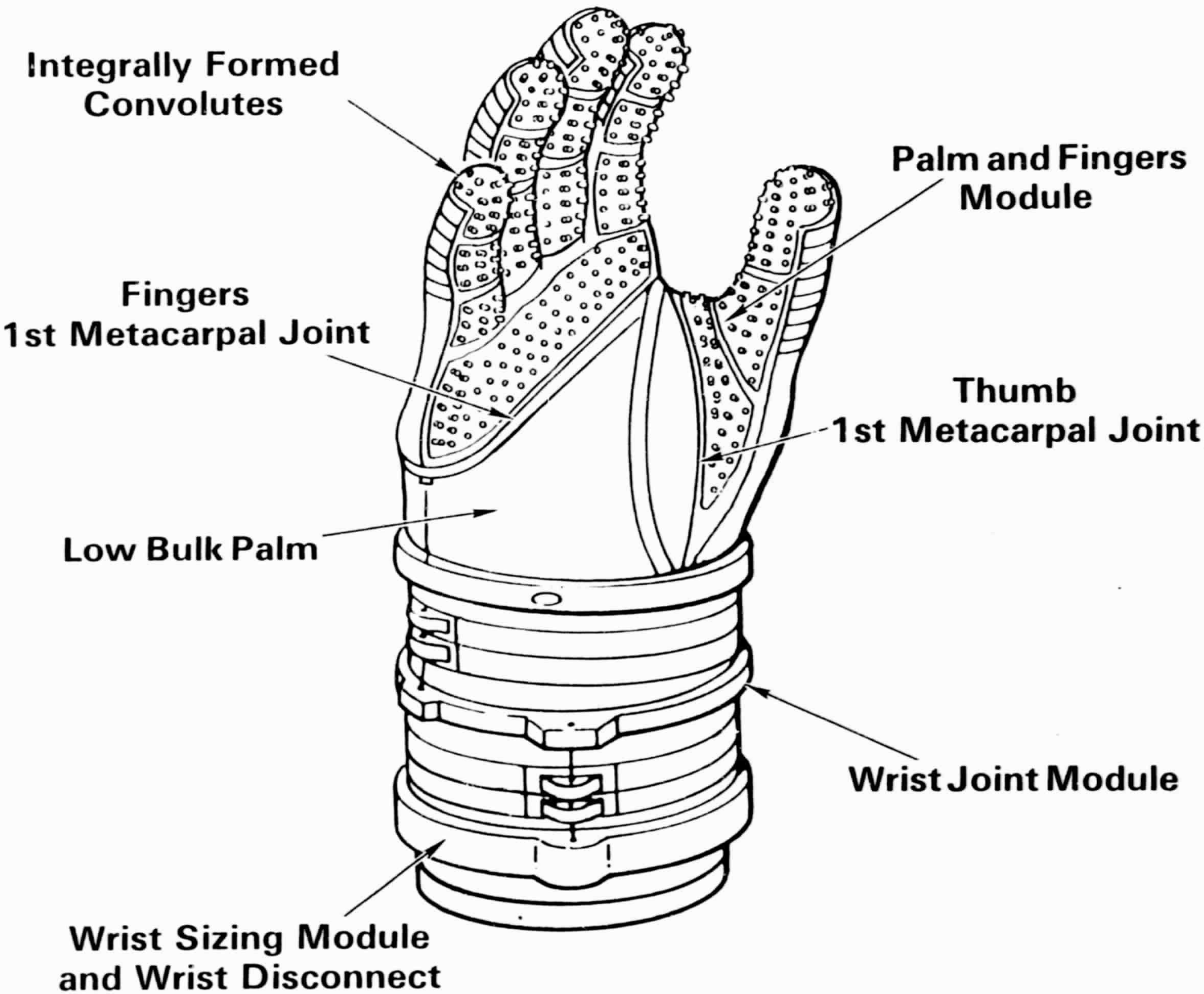
- Glove dsign must consider the adverse effort of thermal insulation on tactility. Tactility is not required anywhere else in the ECWS.

- Glove design must consider heat conduction for up to two minutes as a major avenue of heat transfer. Thermal radiation is the major avenue of heat transfer elsewhere in the EVA enclosure, except for short term contact (on the order of seconds) with hot or cold structure.

- The potential adverse effect of thermal insulation or mobility range and effort is of concern everywhere in the design of the ECWS, but nowhere is it more critical than in the gloves. Hand motions will be among the most frequently performed EVA motions, and the hands will be subject to fatigue at best. Anything which increases hand fatigue will reduce EVA productivity by requiring more frequent rest periods, and, at worst, will promote tool misuse and slippage, perhaps with safety consequences.

The EVA enclosure is expected to derive its thermal protection from the THRO overgarment, whose design approach to thermal, solar radiation and protection from the mechanical hazards of the workplace is epxected to be a multi-layered construction of insulation and protection material selected for the purpose. The problems with this approach for glove design are that it will be too bulky to make the sharp, closely-spaced bends required of the hands, and its layered construction is resilient, allowing it to compress under pressure. This resiliency has two

GLOVE DESIGN CONCEPT



disadvantages for EVA gloves. The first is that resiliency reduces tactility or "feel" by absorbing motions and masking local contact forces and surface textures. The second is that compressing layers of thermal insulation significantly increases the thermal conductivity. Typical multi-layered insulations increase approximately one to two orders of magnitude in conductivity between being unloaded and being compressed to 2 psi, the expected EVA glove grip pressure. By contrast, the ideal glove insulation material would be both highly flexible for joint mobility, and yet would have minimum compressibility to retain its tactility and insulation properties.

A candidate approach to EVA glove insulation approximates this ideal as follows. The insulation consists of short, stiff elastomer fingers or pins, molded integrally with the outer layer of the glove laminate. By confining the pins to the interjoint areas of the palm fingers and back of the hand, joint mobility is retained. Since the pins are not interconnected, they do not impair the flexibility of the underlying laminated glove wall. Each pin is relatively incompressible, compared to layered insulation, and thus transmits all forces back to the laminate without attenuating accompanying motion. This feature should foster tactility.

The length, diameter and spacing of the pins determine their insulating qualities, is shown in the accompanying graph. To support grip and tactility requirements, pin spacing should be fairly close, on the order, perhaps, of 5 to 8 pins per inch. Since the pins are insulators against conducted heat, it follows from the graph that the closer the pin spacing, the longer and/or more slender each pin must be. Grip and tactility influence the idea choice of pin proportion. For example, the closest pin spacing for tactility is 8 pins per inch, as this coincides with the spaceing of the pressure sensation receptors in the skin of the fingers, which sets the minimum spaceing between two objectives that can be resolved by touch. To meet the insulation requirements at this pin spacing requires pin of 0.06 in. length and 0.03 in. diameter. Such a proportion may allow excessive pin bending under load, with asubsequent "spongy" feel and "squirmy" grip. By contrast, if the pin spacing were increased to 5 per inch, pin proportions would become 0.04 in. diameter by 0.04 in. long. Pins of these proportions will bend less, reducing the tactile sponginess and stiffening the grip. Overall tactility is epxected to be enhanced by reducing the sponginess, even at some loss of tactile resolution.

ECWS GLOVE CONCEPT (Continued)

The thermal design basis of the EVA glove concept is as follows:

- The human body strives to maintain blood temperature at 98.6°F. The comfortable hand skin temperature range is 83 to 84°F.

- Discomfort is produced commensurate with the departure of the hand skin temperature from the comfortable range.

- The maximum level of discomfort that can be sustained for two minutes or more corresponds with high and low hand skin temperatures of 113°F and 50°F. These are the limits to be used for EVA glove design. Beyond these limits the discomfort (pain) increases very rapidly, permitting only short exposure durations. For example, one can withstand a hand temperature of 120° for only approximately 12 seconds.

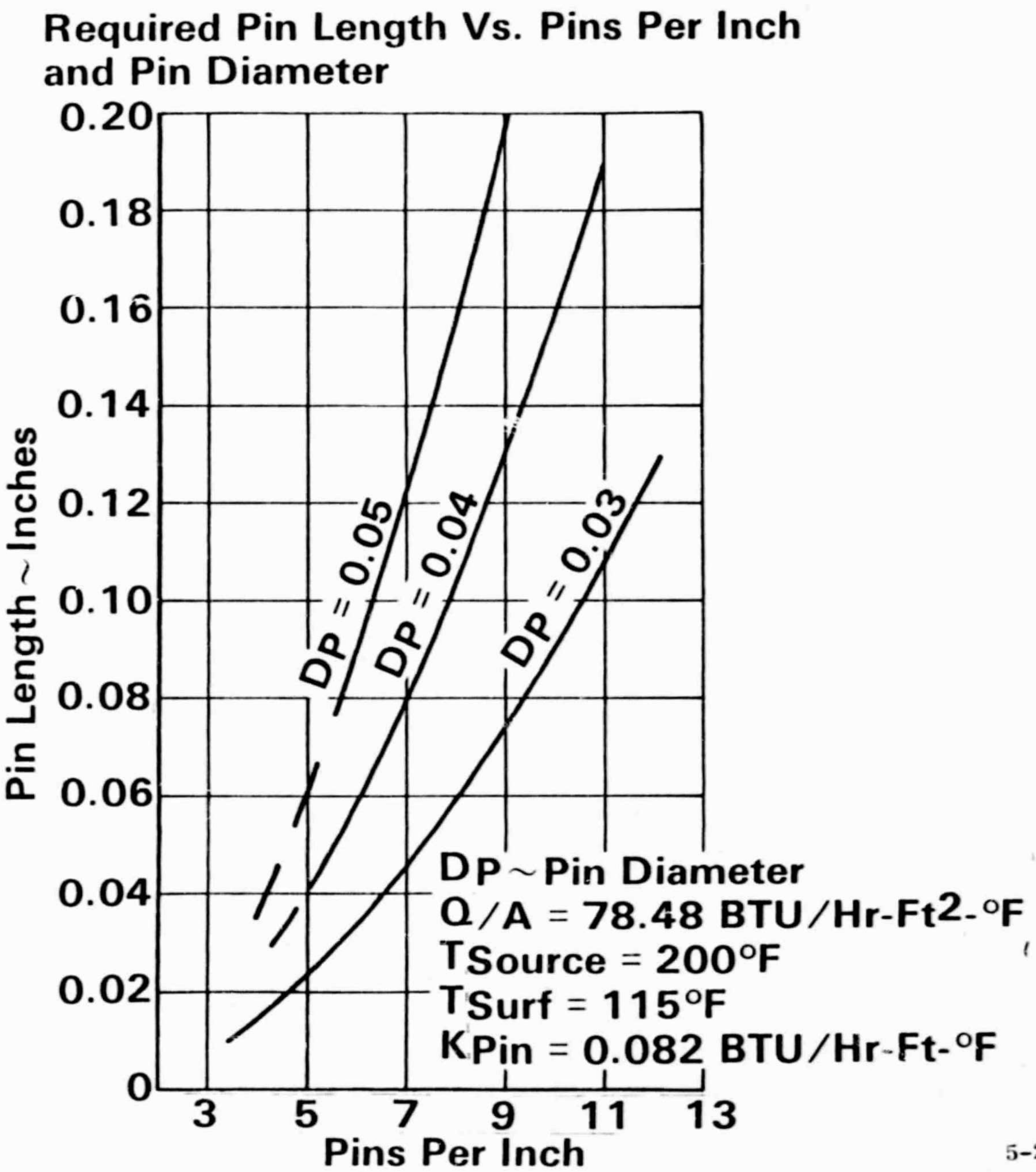
- Glove insulation design is driven by the +200°F surface touch temperature requirements.

- On the basis of the above, using an assumed glove laminate wall thickness of 0.030 in., an uninsulated glove would protect against a maximum surface touch temperature of only 115°F. Thus, a practical EVA capability requires that insulation be provided at all times. This is a driving consideration in concepting the insulation as an integral, inseparable part of the glove wall laminate.

- Thermal radiation requirements would be met by including radiant reflective layers within the laminate, thus providing thermal radiation protection over the entire glove surface.

- The requirement to handle objects occasionally at +450°F would be met by using a protective mitten.

GLOVE HEAT TRANSFER CHARACTERISTICS



ECWS GLOVE CONCEPT (Continued)

Workplace Hazards

Workplace hazards subject the EVA glove to damage from cutting, puncture and abrasion. Laminated fabric construction exhibits good intrinsic abrasion resistance when the fabric can deflect and "flow" over the rough surface, without snagging on small projections, in much the same way as a rubber boat slides over a sand bar in shallow water, or incurs minimal damage with repeated beachings.

Resistance to puncture and cutting can be improved by embedding bands of fine wire mesh within the laminated structure. The mesh would be confined to the interjoint areas of the fingers, palm and back of the hand, and left out of the joint areas, so as to retain the joint flexibility. This construction is analogous to steel-belted radial tires, in which the wire mesh belts protect the treads from penetration, but retain the flexibility of the sidewalls. The insulating pins also contribute to workplace hazard protection by standing the glove wall away from burrs and splinters on the work surfaces. In addition, the pins themselves offer an abrasion-sacrifice surface.

By coloring the outer layers of the EVA glove lamination in highly contrasting colors, surface damage can be made highly visible, with the depth of damage being indicated by the color of the layer exposed. Layer thicknesses would be designed to reveal superficial surface damage before significant structural or thermal properties degradation occurs. Thus, a worn out or damaged glove module would be replaced before it becomes unsafe to use. This is analogous to the tread wear bars in automobile tires that signify tire replacement when only 2/32 in. of tread remains.

Solar Radiation

Radiation protection requires incremental surface mass as follows:

Orbit Inclination, °	28 1/2		55		0
Altitude, Km	400	500	400	500	30K
Additional glove shielding required gm/cm^2	0	0.2	0.4	0.6	1.1

ECWS GLOVE CONCEPT (Continued)

Unlike heat conduction, solar radiation is not a contact phenomenon, and cannot be dealt with by using insulating standoffs. Solar radiation is omnidirectional, and requires 4 steradian shielding. Hence, the addition of mass uniformly around the entire glove is required. Since it is recognized that the presence of material, especially layered material, will reduce tactility and flexibility, as previously discussed, it is important to add only the amount of radiation shielding material required to permit EVA work in a particular construction orbit. As the table below shows, no additional solar radiation shielding is required at the 28 1/2° 400 km orbit. Since this orbit is potentially t"the construction orbit", most EVA construction is expected to occur here. Thus it is important that the basic EVA glove have no intrinsic additional radiation protection, but rather, have the provision for adding just the amount of additional radiation protection required for EVA in other orbits.

The most flexible radiation shielding material should be used, because of the sharp, closely spaced joint bends previously discussed. Chromel R fabric is the best choice in this regard thus far identified. The number of layers of fabric for each orbit considered is as follows:

Orbit Inclination, °	28 1/2		55		0
Altitude, Km	400	500	400	500	36K
Number of Plies of Chromel R required for radiation shielding	0	3-4	6-8	9-11	16-20

The approach to glove radiation shielding differs from that for the rest of the EVA enclosure in that the glove radiation shielding provides only radiation shielding. It performs no thermal insulation function, as the insulation is intrinsic in the glove laminate. Thus, for equivalent radiation shielding properties, the glove radiation overgarment is expected to be considerably thinner and more flexible that the THRO for the rest of the EVA enclosure. This approach represents the best compromise, identified to date, for providing radiation protection, with the least degradation to tactility and mobility.

MANUAL TOOL ADAPTER

The manual tool adapter represents an alternative for overcoming some potentially stubborn shortcomings inherent in EVA gloves. These shortcomings will become increasingly significant with EVA construction, with its requirements for daily EVA. The problems with gloves are that they may remain too stiff and bulky to be comfortable and to permit repetitive flexure without hand fatigue; and yet they are prone to puncture and abrasion. They do not protect against radiation without adding additional bulk and stiffness. Glove design represents a compromise between the conflicting requirements of dexterity and protection, and to favor one adversely affects the other. Yet for EVA construction it would be highly desirable to improve both. The tool adapter described herein offers this opportunity.

The accompanying chart highlights structure fastening and alignment tasks translated into specific grips and motions for the purpose of defining tool adapter requirements.

HAND MOTIONS REQUIRED TO ASSEMBLE AND CHECKOUT SPACE STRUCTURES

Fastening and Alignment Tasks	Hand Motion					
	Engage Fasteners & Turn Finger-Tight	Tighten with Screw-Driver Motion	Tighten with Ratchet-Wrench Motion	Delicate Grip w/ Thumb & Index Finger	Moderate Grip w/ Thumb & Other Fingers	Hand Grip w/ Finger Thumb & Palm
Anchor Structure to Assy Fixture	X		X			X
Hold Structural Elements Together, Then Tighten Captive Bolts	X		X			X
Clamp Box Beam Sections Together to Form Long Beams	X		X			
Anchor and Align Amplitrons, Sensors & Thrusters	X	X				
Anchor Electronic Black Boxes	X	X				
Fasten to Structure						
Wave Guides					X	
Wire Harnesses		X		X		
Solar Blankets				X	X	
Solar Reflectors				X	X	
Radiometer & MBL Panels	X		X			
Align Structure with Jackscrews			X			X

TOOL ADAPTER REQUIREMENTS

The following requirements define the basic operating environments and use modes to guide the concepting of a practical tool adapter.

1. General

   The tool adapter shall supplement the EVA glove worn on the preferred hand, that is, the tool adapter shall be worn in place of the right hand glove by a right-handed crewman for certain EVA sorties. This is consistent with the observation that the repetitive, highly controlled finger and hand flexures are performed with the preferred hand while the other hand provides support in terms of push, pull or grip, but is not required to perform continuous repetitive flexures or delicate motions that are fatiguing. This also leaves the other hand free in its glove to operate the life support equipment controls and to cope with emergencies. This latter point is particularly significant in reducing the psychological stress of an emergency. Having one "natural" hand available should increase the crewman's effectiveness in handling unforeseen situations.

2. Motions

   Three general types of motions shall be produced via the tool adapter:

   - Rotary Motion, as required to drive and torque fasteners.

   - Grip Motion, as required to grasp objects.

   - Push and Pull Motions, as delivered by a flat, outstretched hand or by the fingers placed behind an object, in a direction normal to the plane of the hand.

3. Actuation

   Actuation of the tool adapter shall be by the preferred hand. This precludes power assists in the interests of simplicity, reliability, maintainability and freedom from interfaces other than at the wrist disconnect of the EVA enclosure.

TOOL ADAPTER REQUIREMENTS (Continued)

4. Magnitude of Forces, Torques and Motion

The range of forces, torques and motions shall approximate those of the human hand to retain as much realism as possible in using the tool adapter.

5. Cycle Life

The tool adapter shall have a cycle life of 5×10^6 cycles. In flight replacement of parts between EVA's shall be permissible. The cycle life is consistent with:

$$10 \text{ missions} \times 154 \frac{\text{EVA's}}{\text{Mission}} \times \frac{480 \text{ mins}}{\text{EVA}} \times \frac{6 \text{ actuation cycles}}{\text{Minute}} = 4.432 \times 10^6 \text{ actuation cycles}$$

6. Temperature Range

The total adapter shall operate in contact with surfaces whose temperature ranges from -180°F to +450°F with contact durations of 2 minutes maximum.

7. Radiation Protection

The tool adapter shall provide radiation shielding equivalent to 1.2 gm/cm^2, which is equivalent to the shielding required of the EVA enclosure at GEO.

8. Leakage

The tool adapter leakage shall be equal to or less than 20 scc/minute of O_2 at an internal pressure of 4.0 psig. This is the same as the leakage value for the Shuttle EMU glove during ground testing.

9. Other Requirements

Other requirements shall be consistent with the "Guidelines and Requirements Document" of the ECWS Study Program in Section 4 of this volume.

TOOL ADAPTER CONCEPT

The tool adapter, concepted to meet the above requirements, is shown in the accompanying cut-away. It consists of a turret enclosing the hand, and is attached to the EVA enclosure wrist via a wrist-bearing disconnect. Thus the turret is free to rotate on the wrist. The turret contains two tools, one for rotary motion and one for gripping. The turret also has one flat surface, co-planar with the grip tool palm for transmitting push forces normal to the plane of the palm. The tools are positioned on the turret in a manner to coincide with a comfortable hand position within the turret. Motion of the tools is produced by corresponding hand motions within the turret. Motion is transferred by freely moving linkages from the hand to the external tools. All seals are rotary, and are of small diameter so as to absorb little torque. Hence, repetitive motions should produce little hand fatigue. The turret itself is a rigid casing capable of withstanding the rigors of the workplace environment. Thus the tool adapter concept should both reduce hand fatigue and increase hand protection with respect to an EVA glove.

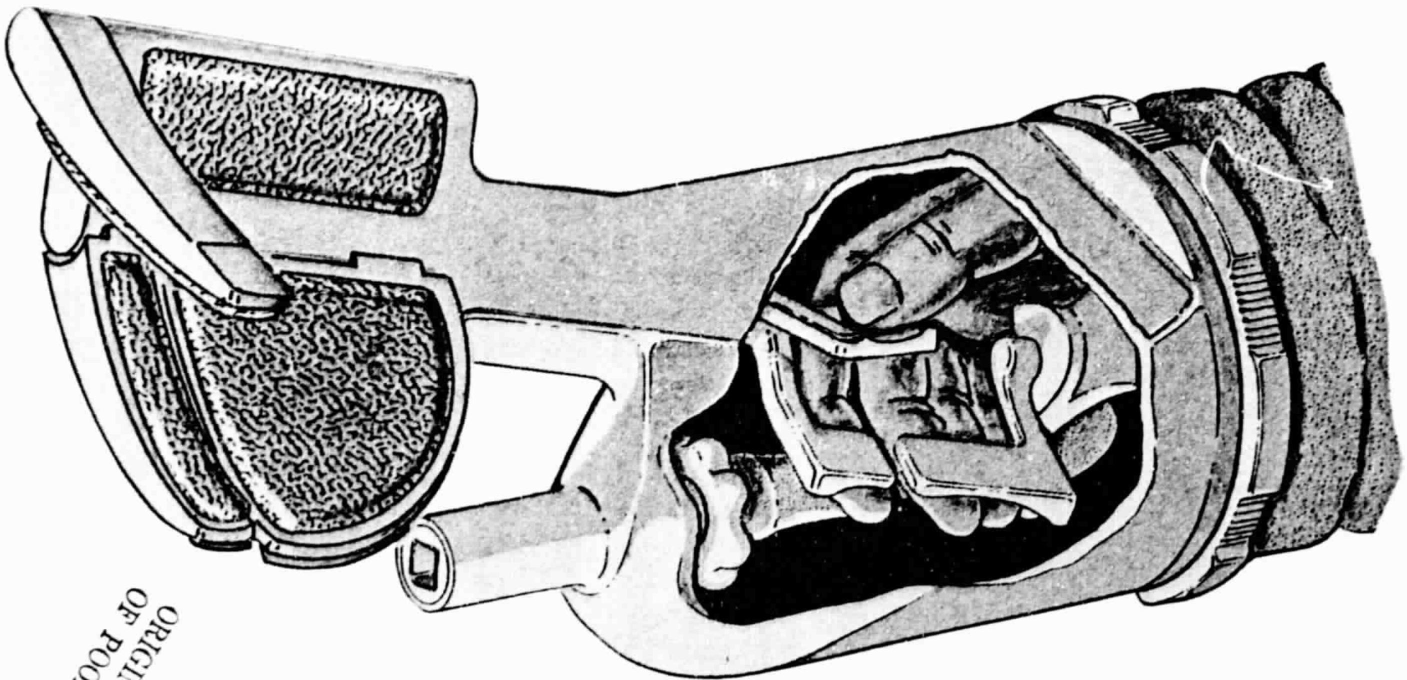
Rotary Motion

The rotary motion tool produces three types of motion namely:

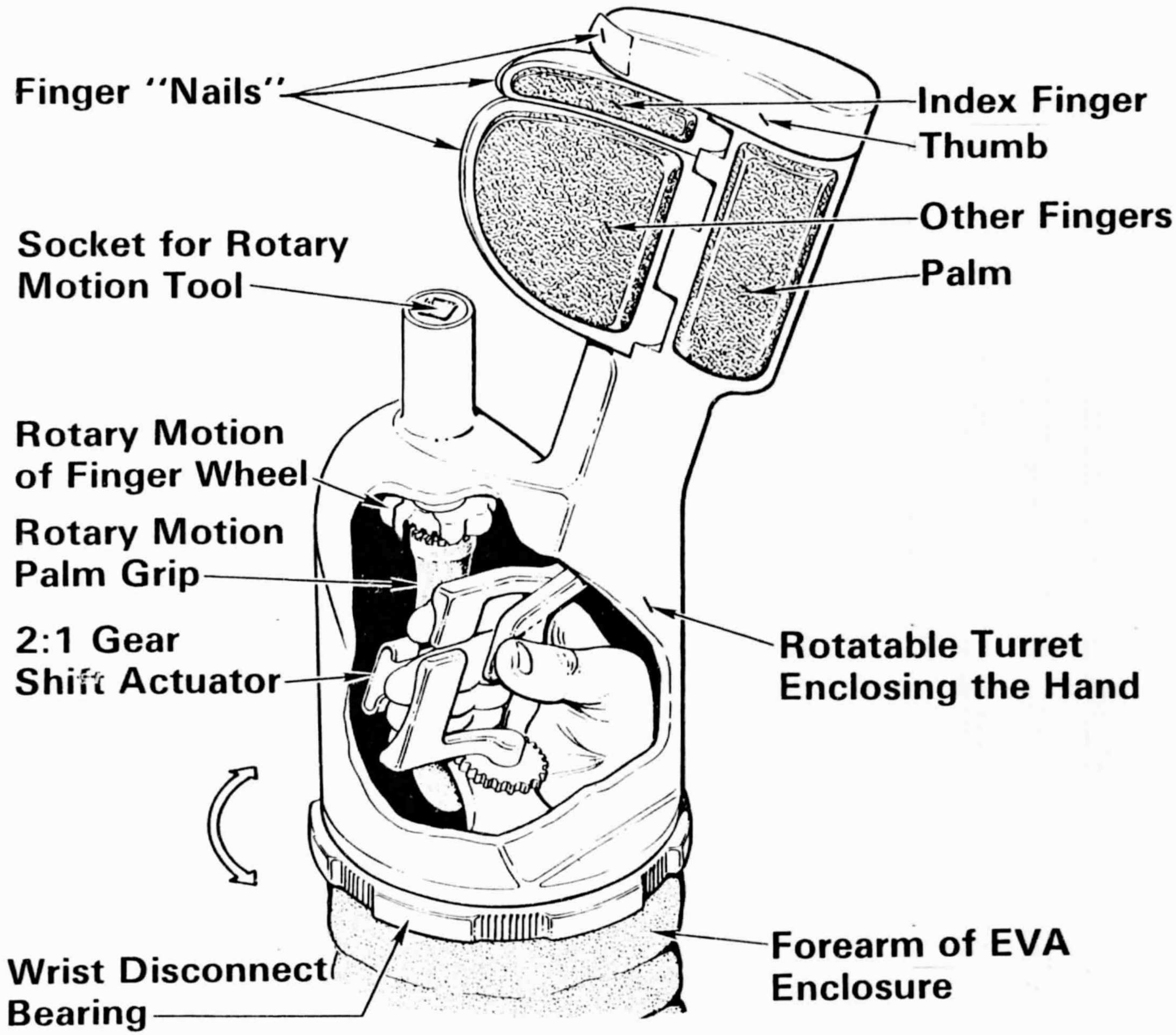
- Low torque, "finger twirling" motion, as required to tighten a fastener "finger tight". This motion is produced within the turret by turning a knobby finger wheel (similar to a valve handle) with the fingertip pads of the thumb and fingers.

- Moderate torque, palm grip with wrist rotation motion as required to tighten a fastener to specified torque levels. This motion is produced within the turret by grasping and turning a palm grip handle about its longitudinal axis. The handle is clutched to the finger wheel with a set of mating face gears. This permits the finger twirling motion to occur without incurring friction drag of the palm grip handle against the palm of the hand.

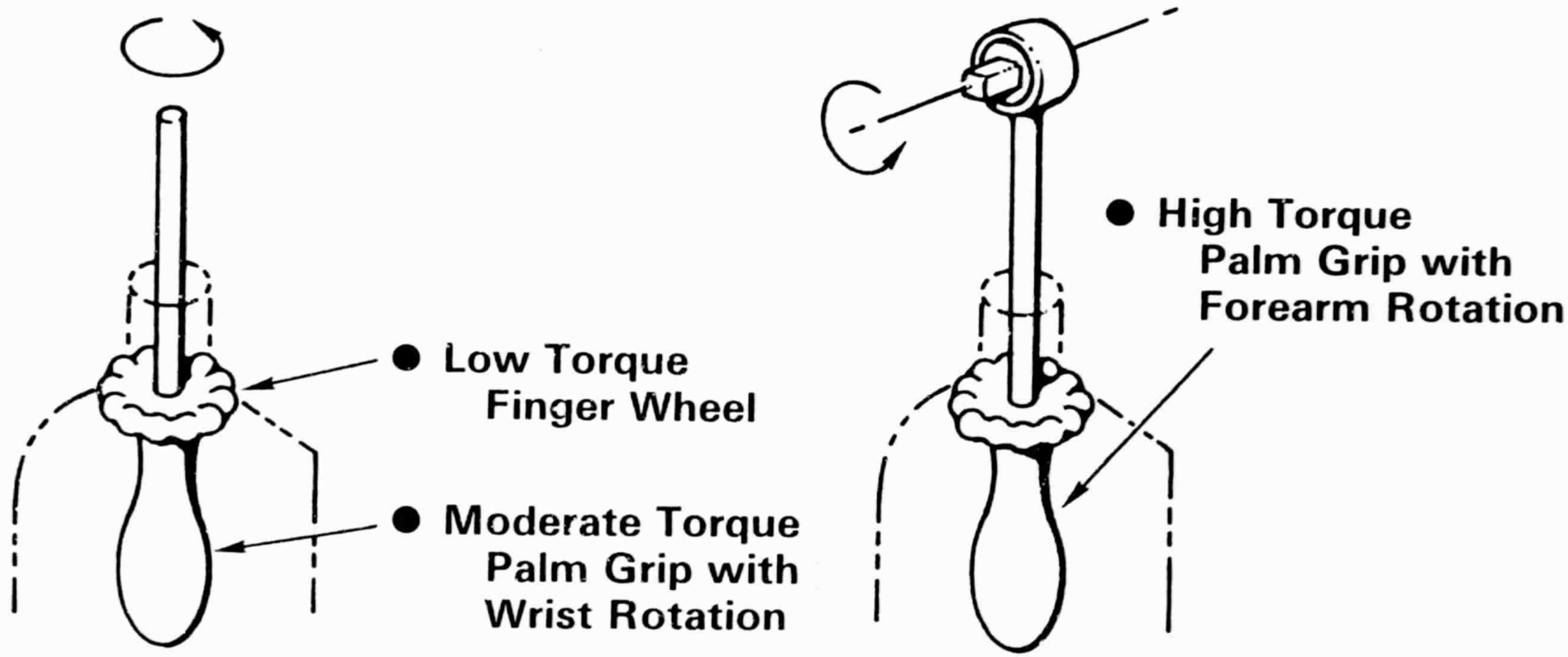
- High torque, palm grip with forearm revolution required to produce torque in the range of up to 100 ft-lb. This motion is produced by grasping the palm handle and applying a whole body push or pull to use the rotary tool as a ratchet wrench.



TOOL ADAPTER CONCEPT



TOOL ADAPTER CONCEPT



TOOL ADAPTER CONCEPT (Continued)

Grip Motion

The grip motion tool produces three types of motion, namely,

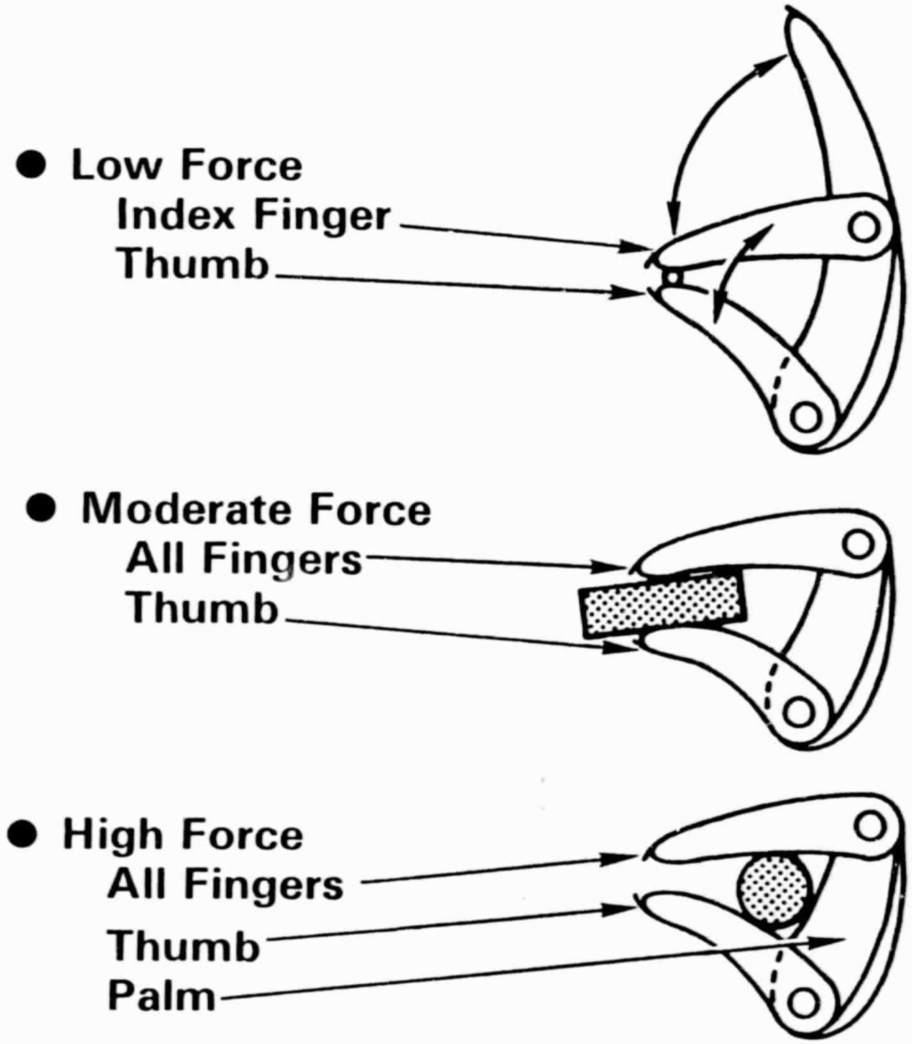
- Low force, delicate grip for small objects using the tips of opposed thumb and index finger of the grip tool. This force is produced within the turret by the crewman's thumb and index finger bearing against the thumb and index finger actuators as is shown.

- Moderate force for objects using the fingerprint area of the opposed thumb and all fingers. This force is produced within the turret by the crewman's thumb, index finger and other fingers bearing against the respective actuators. The actuator for the other fingers is as shown.

- High forces, using the proximal portions of the thumb and all fingers to press objects against the palm. These forces are generated using the same actuators used to produce the moderate grip forces. However, if a particularly high grip force is required, a gear shift lever may be moved to engage a 2:1 grip force multiplication between the palm and other fingers. This mechanism is also shown.

The grip tool has padding on the palm, thumb, index finger, and other fingers. This padding approximates the compliance of human hand tissue and provides both a high coefficient of friction and force feedback to enhance the realism of using the tool adapter. The thumb, index finger and other fingers are also equipped with "fingernails" for light duty prying.

GRIP MOTION



Low Force
Index Finger
Thumb
Moderate Force
All Fingers
Thumb
High Force
All Fingers
Thumb
Palm

TOOL ADAPTER CONCEPT (Continued)

Grip Motion Actuators

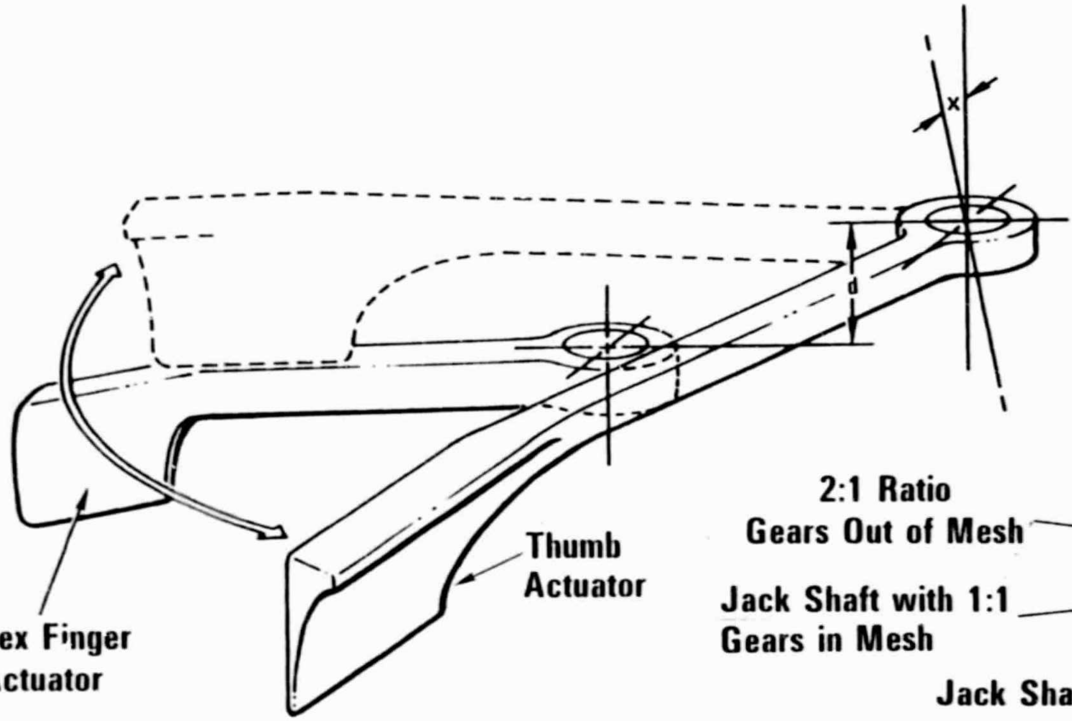
The actuators are shaped as shown. The actuator pivot points coincide with the hinge points within the hand to make the actuation track the finger motions. This is important in making the actuators comfortable to use, as well as to have the grip tool follow the motions of the crewman's hand faithfully. The thumb and index finger actuators are offset from one another in both elevation and axis of rotation angle so that the two actuators will not interfere with each other in the outstretched hand position, and yet the two actuators will come together for the light grip force when the fingers are rotated into that position.

The actuator for the other fingers is as shown. The axis of this actuator is coincident with the axis for the index finger actuator. However, since the crewman's hand occupies the space between the index finger actuator and the other finger actuators, motion from the other fingers actuator must be routed behind the crewman's hand. This is accomplished with two sets of gears and a jack shaft.

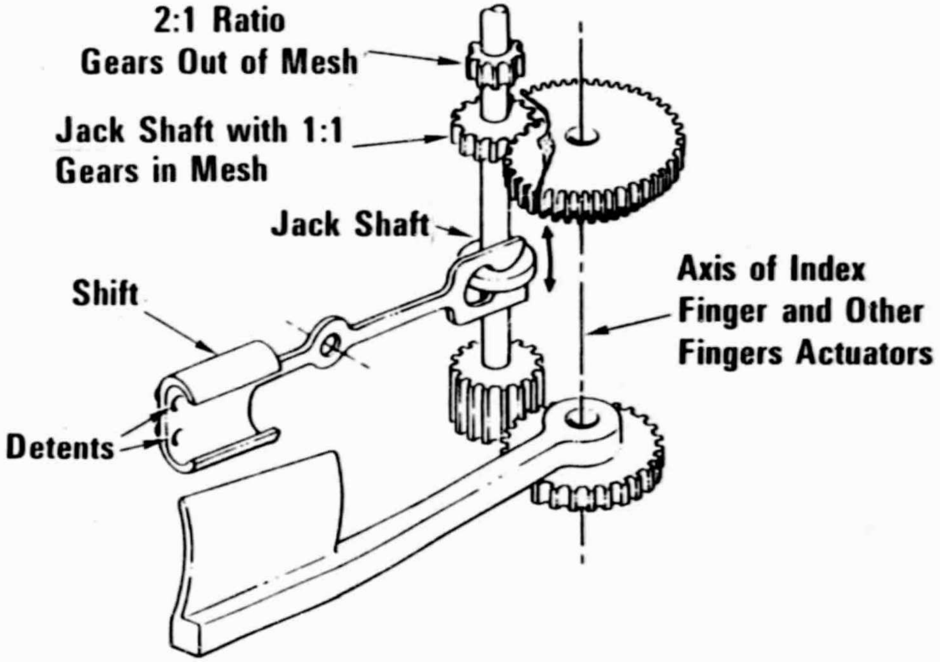
The presence of the jack shaft makes possible the inclusion of a selectable 2:1 force multiplier as shown. Moving the jack shaft axially causes either a 1:1 or a 2:1 gear set into mesh. The axial motion is accomplished via a gear shift lever located behind the crewman's hand, and actuated with his fingers. The shift is retained in its selected position by engaging one of two detents.

Since the gears rotate no more than 90o, teeth on three-quarters of the gear circumference are not normally used. Hence, excessive wear or breakage of gear teeth can be repaired on orbit by reindexing the gears one quadrant. This operation may be performed three times on any set of gears, and is equivalent to provisioning three sets of spare gears.

GRIP MOTION ACTUATORS



Thumb Actuator Rides Over Index Finger Actuator in hand-Outstretched Position by Locating Thumb Actuator Above Index Finger Actuator by a Distance "d". Thumb Actuator Enters Plane of Rotation of Index Finger Actuator by Tipping Axis of Thumb Actuator Toward Palm by Angle X.



POWERED TOOL ADAPTER

The powered tool adapter represents an additional new technology concept which will enhance the task capabilities of the EVA construction worker. This approach can be used in conjunction with EVA glove or in place of the glove to enable the worker to use various power tools with a minimum of physical exertion. The powered tool adapter described herein lends itself to an external portable mode useful for specific tasks, and to an enclosed mode integral with the EVA pressure enclosed mode integral with the EVA pressure enclosure to facilitate repetitive bolting, fastening and cutting type activities.

Future construction space, especially when engaged in on a large scale basis, will require the use of power tools. Typical tasks will require the use of power assisted wrenches, screwdrivers, drills, and saws. The reciprocal and rotary motion capability of the powered tool adapter will accommodate the power tools required for projected construction activities on representative space structures.

POWERED TOOL ADAPTER REQUIREMENTS

The following requirements define the basic operating environments and use modes to guide the concepting of a practical powered tool adapter.

1. General

The powered tool adapter shall replace the EVA glove worn on the preferred hand, that is, the tool adapter shall be worn in place of the right hand glove by a right-handed crewman. This is consistent with the observation that the repetitive, highly controlled finger and hand flexures are performed with the preferred hand while the other hand provides support equipment controls and to cope with emergencies. This latter point is particularly significant in reducing the psychological stress of an emergency. Having one "natural", but gloved hand available should increase the crewman's effectiveness in handling unforeseen situations. Another option is to develop the powered tool adapter for use with the EVA glove, i.e., making it completely independent of the EVA pressure enclosure.

2. Motions

Two general types of motions shall be produced via the powered tool adapter:

- Rotary Motion, as required to drive and torque fasteners
- Reciprocating Motion, as required in sawing or cutting activities.

3. Actuation

Actuation of the powered tool adapter shall be by the preferred hand. Design shall permit the index finger to depress a trigger switch to initiate operation of the powered tool adapter. A switch shall be incorporated to provide for operation at three levels of torque. The powered tool adapter shall also be capable of reverse mode operation.

4. Magnitude of Forces, Torques and Motion

The range of forces, torques and motions shall be commensurate with those of terrestrial hand held power tools, or as required by space applications.

POWERED TOOL ADAPTER REQUIREMENT (Continued)

5. Working Life

The powered tool adapter shall have a working life of 1.5×10^4 hours. In flight replacement of parts between EVA's shall be permissible. The working life is consistent with:

$$10 \text{ missions} \times 154 \text{ EVA's/mission} \times 8 \text{ hours/EVA} = 1.232 \times 10^4 \text{ hours}$$

6. Temperature Range

The powered tool adapter shall operate in contact with surfaces whose temperature ranges from -180° to +450° with contact durations of 2 mintues maximum.

7. Radiation Protection

The powered tool adapter shall provide radiation shielding to the crewman's hand equivalent to 2.0 gm/cm^2, which is equivalent to the shielding required of the EVA enclosure at GEO.

8. Leakage

The powered tool adapter leakage shall be equal to or less than 20 scc/minute of O_2 at an internal pressure of 4.0 psig. This is the same as the leakage value for the Shuttle EMU glove during ground testing.

9. Debris Collection

There shall be a positive means of containing debris generated by the use of the powered tool adapter in performing operations that produce material chips or the like.

10. Other Requirements

Other requirements shall be consistent with the "Guidelines and Requirements Document" of the ECWS Study Program, in Section 4 of this volume.

POWERED TOOL ADAPTER CONCEPT

Two versions of the powered tool adapter concepted to meet the above requirements are shown in the accompanying illustrations. The version to be used with the EVA glove consists of a tool handle with a trigger switch for normal operation and a thumb switch allowing operation at three different torque levels. The tool handle is symmetrical with a folding leverage bar built into one side so that the crewman can use it with his preferred hand while steadying it with his other hand. The power tool module snaps onto the tool handle actuator and the various mechanical tool modules fit into the power tool module.

The second version consists of a hand pressure enclosure (HPE) replacing the glove for the preferred hand. The tool handle with linear actuator is built into the HPE. The HPE consists of a turret enclosing the hand attached to the EVA pressure enclosure via a wrist bearing disconnect. Thus, the HPE is free to rotate on the wrist. As in the version described above, the HPE is symmetrical with a folding leverage bar built into one side. This allows the crewman to use the powered tool adapter in space much as he would a large drill on earth with one hand squeezing the trigger and the other steadying the powered tool adapter. See Figure 3. As above, the power tool module snaps onto the the tool handle actuator with the mechanical tool modules locing into the power tool module. The HPE turret is a rigid casing capable of withstanding the rigors of the workplace environment. The concept should therefore both reduce hand fatigue and increase hand protection in comparison to an EVA glove.

The powered tool adapter concepted herein produces rotary and reciprocal motions. While limiting the tool adapter to those motions might appear to be a restrictive limitation, the following paragraphs describe the motions and their wide range of capabilities.

POWERED TOOL ADAPTER CONCEPT (Continued)

Rotary Motion - The powered tool adapter produces three types of rotary motion, namely:

- Low Torque - "Free Spinning" motion, as required to tighten a fastener "finger tight" or screw a nut or until met by frictional resistance. To achieve this motion requires pushing the torque switch to the low-torque position (with the thumb) and ensuring that the rotary motion switch is on. In addition, a selection switch on the side of the handle allows for a reverse (counter-clockwise) rotary motion mode. Depressing the trigger switch then activates the low torque rotary motion.

- Moderate Torque - Rotary motion required to tighten a fastener to specified torque levels. This motion requires having preselected the moderate torque position, ensuring that the motion switch is on rotary, and that it is in the forward (or reverse), mode. The trigger switch activates the desired motion.

- High Torque - Rotary motion required to produce torque levels up to 70 ft-lb. This motion requires having the torque switch in the high torque position, the motion switch on rotary, and the forward (or reverse) mode switch on as appropriate. The trigger switch activates the desired motion.

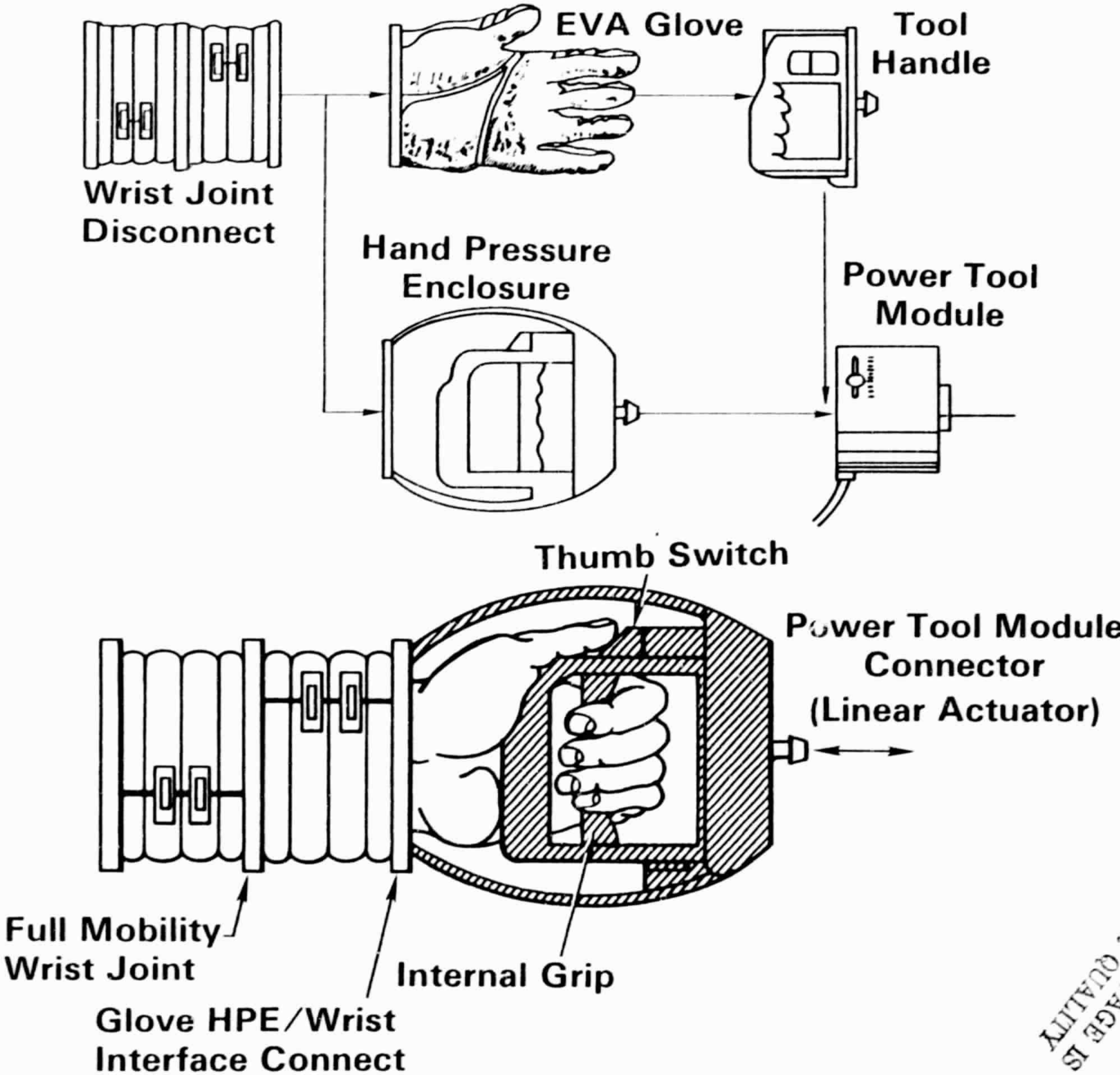
The rotary motion tools and their integration into the power tool module is depicted in the accompanying illustration.

Reciprocating Motion - The powered tool adapter produces a variable speed reciprocal motion.

- Variable Speed - Back and forth motion, as required to cut or saw. To achieve this motion requires preselecting the reciprocating motion position of the motion switch and dialing the desired speed. Depressing the trigger switch activates the desired cutting action.

The reciprocating motion tools and their integration into the power tool module is depicted in the accompanying illustration.

POWERED TOOL ADAPTER CONCEPT



POWERED TOOL ADAPTER CONCEPT (Continued)

Options - Several additional features may be incorporated into the powered tool adapter concept namely:

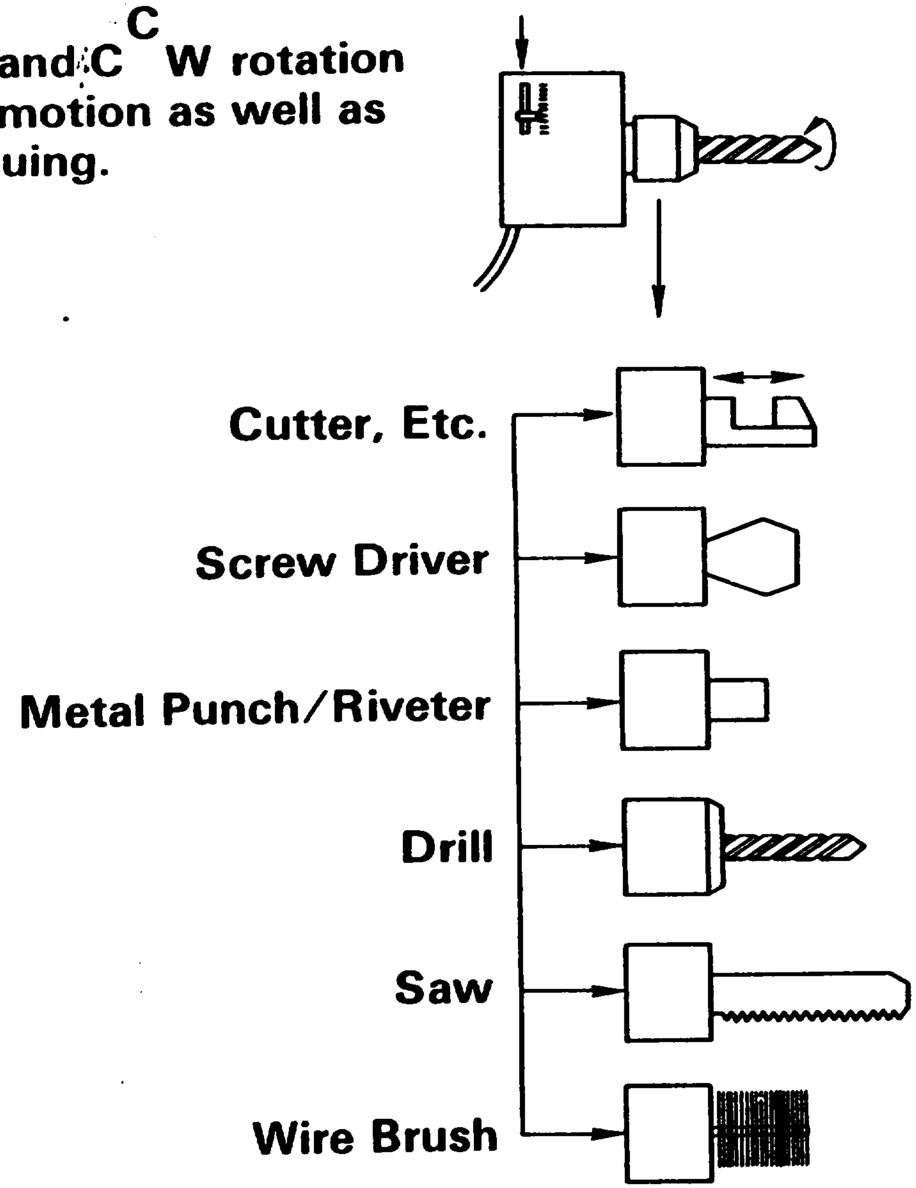
- Torque Level Dial - A dial can replace the torque level switch settings such as is used on a food blender.

- Impact Wrench - An impact wrench capability could be incorporated into the design of the powered tool adapter. This feature would allow forward and reverse impact torques up to 150 in-lb as is found on commercially available hand power tools. Provisions would have to be made to provide for selecting this mode of operation.

- Riveter - A punch rivet capability could be included in addition to the others described. Providing this would involve a significant design change but would add another dimension to the fastening capability of the powered tool adapter.

- Other - Additional power tool module options could include: (1) a rotary file, (2) a metal punch, (3) a reamer, (4) a wire brush, (5) a belt sander, and (6) a countersink.

Tool Module — Provides CW and CCW rotation or reciprocal motion as well as precision torquing.

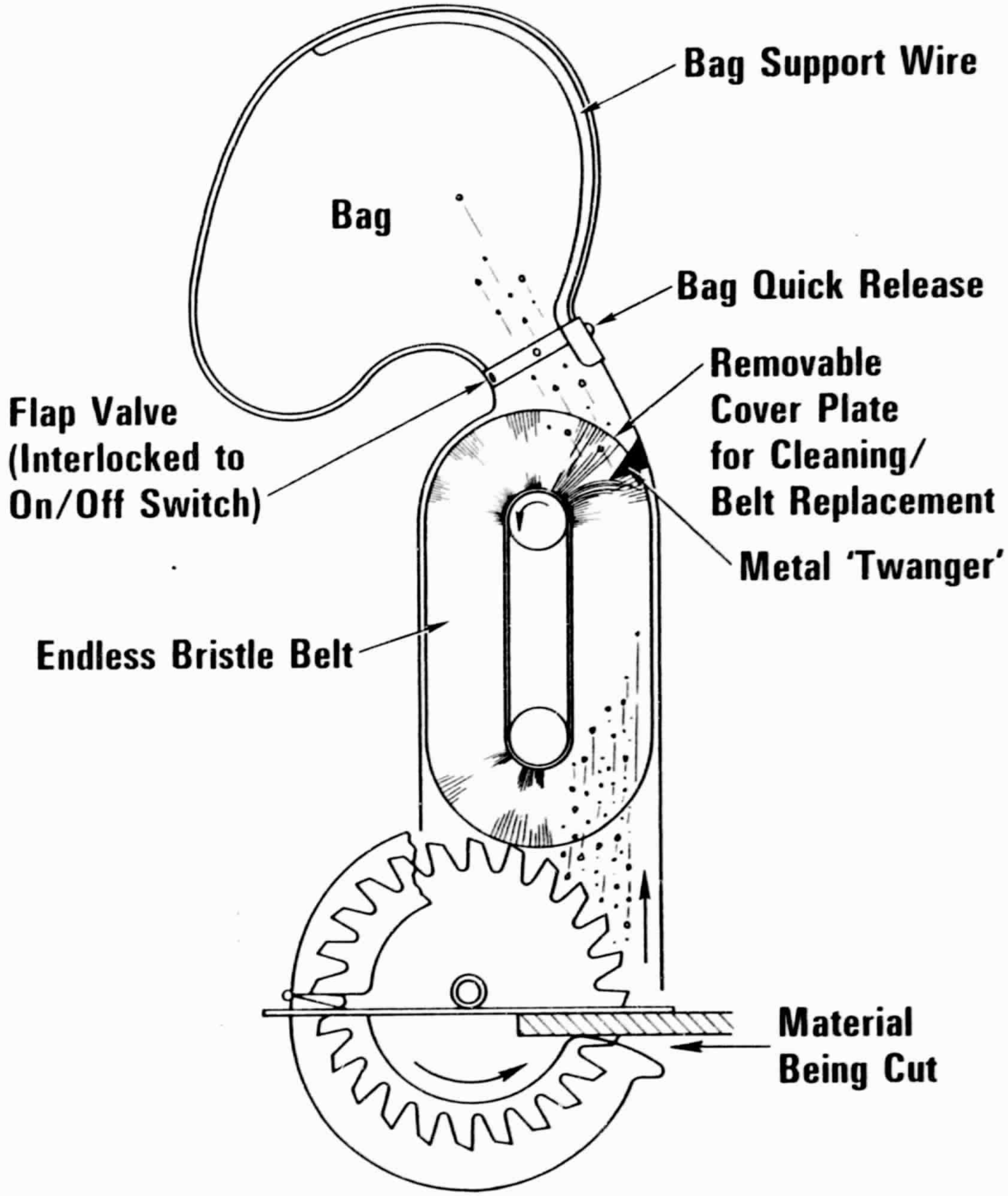


POWERED TOOL ADAPTER CONCEPT (Continued)

- In conjunction with the motions and capabilities of the powered tool adapter described above, it is imperative that there be a positive means of controlling debris. Because there is no gravity and no atmosphere, conventional methods which rely on gravitation and suction will not work. Several ways of coping with the problem include the use of magnetic attraction, electrostatic charges, and the momentum of the particles. The latter appears to be the simplest method. The accompanying figure shows a concept for a collection device which employs the momentum of the particles to effect their own capture.

- In this concept the saw blade propels particles into an endless bristle belt. The belt traps the particles and delivers them to the mouth of the collection bag. A "twanger" bar bends the bristles. Releasing the bristles causes the particles to be propelled into the collection bag. A flap valve closes off the bag when the tool is turned "off", keeping the particles in the bag.

REPRESENTATIVE SAW DEBRIS COLLECTOR



PORTABLE WORKSTAND

Workstands are a necessary adjunct to EVA construction as they provide anchorage for the crewman's restraints, locating him at the worksite, and grounding his force and torque reactions as he proceeds with his EVA task. The workstand also provides anchorage for work lights, and storage or tethering points for tools and work materials.

Portable EVA workstands will be required to support space construction activities in two important regards:

- During early phase of a construction project, before permanent work stations have been erected at long-term worksites.

- During all phases of a structure's useful life namely, construction, checkout, and maintenance to support EVA at infrequently visited locations that do not warrant permanent worksite facilities.

Present Shuttle EVA planning has not addressed the problem of providing a workstand containing tools, materials, supplies, restraints and other equipment to support one or several full EVA workshifts at a worksite, although individual elements, such as tools, tethers and restraints are available or are under development. For space construction, however, productivity requirements will demand efficient use of EVA time, and therefore, will favor setting up a temporary worksite in the shortest length of time, and with the minimum numbers of trips between the air lock and the worksite to transport all requisite gear and materials. For example, a worksite at the middle of a TA-2 antenna test article may be 150 m away from the air lock. At a typical translation rate of 0.5 m/sec, a one-way trip to a worksite would take 5 minutes, or 1% of an 8 hour EVA sortie. Each additional trip required would add one round trip of 10 minutes. Thus the productive portion of an EVA sortie would be diminished rapidly as the number of trips to a worksite increases.

The portable workstand concept provides a simple, lightweight platform that integrates restraints, tools, battery, lights and some materials. An EVA crewman, wearing the ECWS and carrying the portable workstand, has everything he needs with him to perform useful EVA work.

PORTABLE WORKSTANDS (Continued)

A number of EVA tasks have been identified that either require or imply use of a portable workstand.

- Positioning and installing construction equipment, materials, lighting, work platforms and restraints.

- Specific construction activities such as handling tools and instructions to perform deployment, fabrication and assembly operations.

- Checkout and activation activities, including alignment and adjustment of structure, functional testing and fluid servicing.

- Maintenance and repair activities consisting of fluid replenishing, cleaning, functional testing, replacement or realignment of equipment modules and repair of structural damage.

These tasks span the useful life of a space structure, and cover the range of space-structure-oriented EVA requiring the support provided by a lightweight, simple portable workstand.

PORTABLE WORKSTAND REQUIREMENTS

The following requirements define the general characteristics of the portable workstand as well as define its performance and environmental parameters to guide the concepting process.

1. General

   The portable workstand shall be a collapsible platform, providing foot and waist restraint for one EVA crewman. It shall provide storage space for typical (TBD) quantities of tools, portable lighting, electric power and dispensing of small hardware items, as well as anchorage for any carry-along part of the ECWS LSS, such as a radiator heat sink or basic services (oxygen, cooling and power) package.

   The portable workstand shall also be a very simple, lightweight structure, adjustable to fit the projected crewman population.

2. Transportation and Set-up

   The workstand shall be easily transportable to the worksite, erectable and quickly attachable to the space structure by one person.

3. Attachment to Structure

   To minimize the impact on structure weight or complexity, the portable workstand shall minimize the number or weight of any special provisions required to be designed into and included within the space structure and whose sole function is to provide attachment means for the portable workstand. In addition, the portable workstand shall not require the drilling of any holes in the structure nor the permanent attachment of special mounting provisions, in orbit, in order to attach the workstand to the structure.

4. Equipment Positioning

   The workstand shall be designed so that any ECWS LSS equipment anchored to it will be out of the way of a crewman working on the structure or reaching for tools and materials. Radiator mounting provisions shall permit mounting a 3 ft x 5 ft deployed radiator, pointing it away from structure, and rotating it through a solid angle of 2π steradians.

PORTABLE WORKSTAND REQUIREMENTS (Continued)

5. Restraints

The foot and waist restraints shall be engaged and disengaged easily by the crewman. In addition, these restraints shall include a quick release safety feature to enable a second crewman to perform an emergency rescue.

6. Design Loads

The work platform, restraints and vehicle attachments shall be designed to withstand a force exerted in any direction by the crewman of 70 lbs and a torque into the foot restraints of 55 ft-lbs without slipping, changing position or being damaged.

7. Temperature Range

The portable workstand shall not be adversely affected by contact with structure surfaces whose temperature range is +200°F to -180°F. The workstand shall be designed so that its surfaces do not exceed the touch temperature range of +200°F and -180°F.

8. Useful Life

The portable workstand shall have a useful life of 5,000 deployment cycles. This is consistent with

$$\frac{3\ \text{cycles}}{\text{EVA sortie}} \times \frac{154\ \text{EVA sorties}}{\text{Mission}} \times 10\ \text{Missions} = \frac{4{,}620\ \text{deployment}}{\text{cycles}}$$

9. Stowage

The portable workstand shall fold so that it can pass through a 1 m diameter hatch, and shall not exceed 1.5 m in length so that it can be brought inside the air lock.

Requirements 5 through 9 were derived from or previously stated as specific ECWS requirements.

10. Other Requirements

Other requirements shall be consistent with the "Guidelines and Requirements Document" of the ECWS Study Program, in Section 4 of this volume.

PORTABLE WORKSTAND CONCEPT

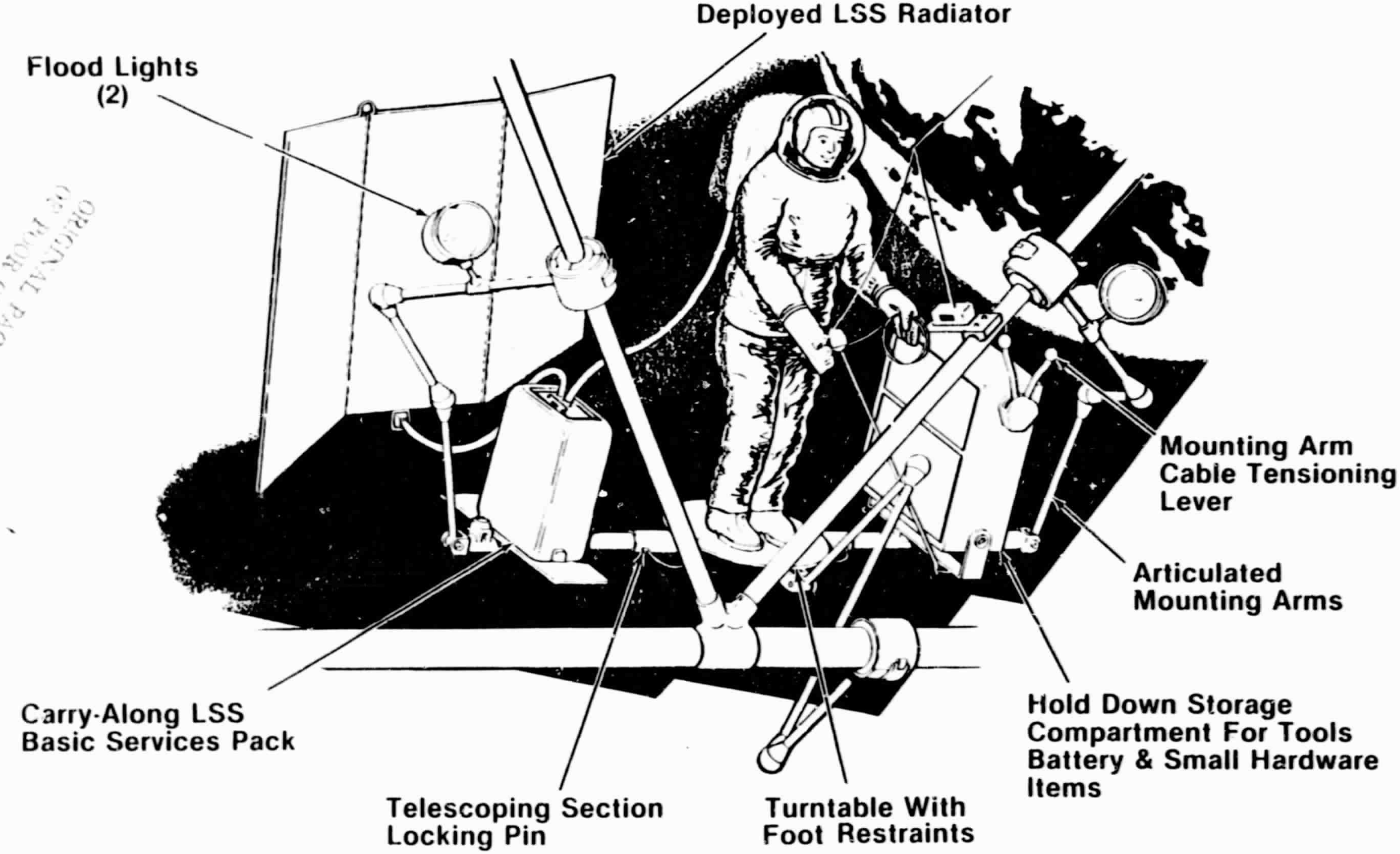
The portable workstand concept consists of four major elements: a telescoping backbone bar, a turntable with foot restraints, collapsible storage chests, and three articulated mounting arms.

The telescoping backbone is the main structural element of the portable workstand. It mounts the turntable, storage chest(s) and articulated mounting arms. It also serves as the anchor point for the LSS radiator, LSS carry-along basic services package, and waist restraint "D" rings.

The waist restraint concept is also shown. The crewman wears two locking "negator" spring elements, each secured to a "D" ring on the telescoping backbone via a snap hook. Low force restraint, as well as mobility, is provided by the constant-force action of the two negator springs, which is independent of how far the restraint is extended. When rigid waist restraint is required, the crewman locks the two negator spring elements, and his waist is thus restrained in that position.

The storage chest can be rotated flat to the platform for stowage and transportation to the worksite. It contains small hardware stowage, batteries for power, tools and lights, and tool storage. It also serves as the mount for the mounting arm tensioning levers. The turntable, which is lockable, has Shuttle step-in type foot restraints. The turntable permits the crewman to rotate without disengaging his foot restraints or twisting his spine and pelvis excessively.

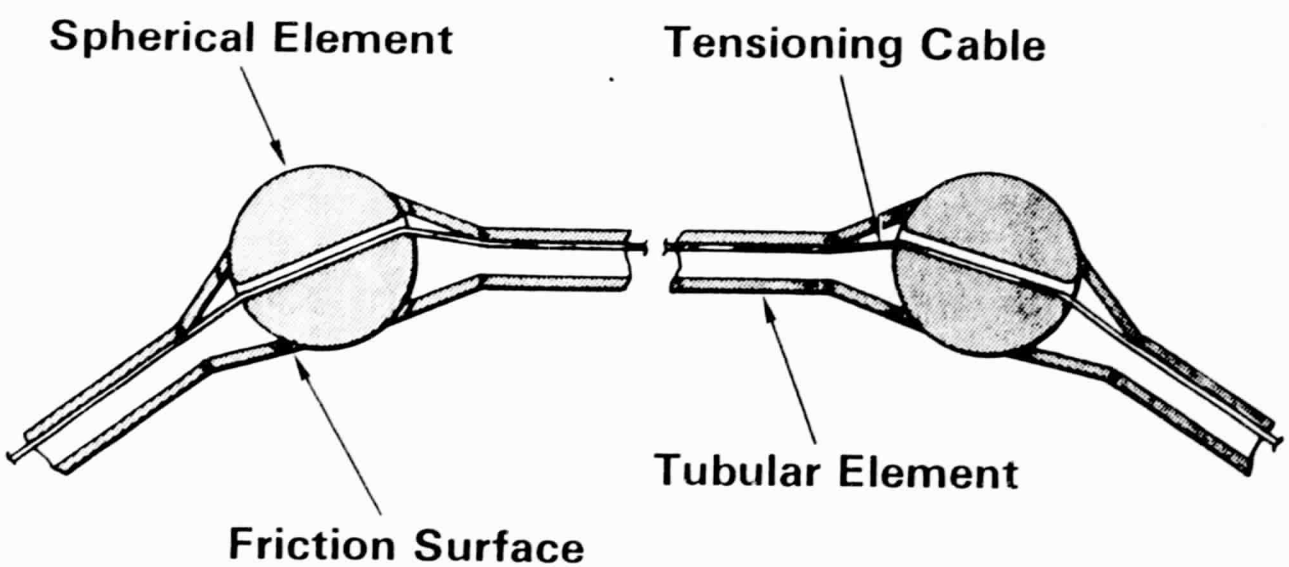
PORTABLE WORKSTAND CONCEPT



PORTABLE WORKSTAND CONCEPT (Continued)

The mounting arms are constructed of alternately arranged tubular and spherical elements, as shown. A cable, running through the center of the elements, ties them all together. Actuating the tensioning lever draws the elements together, locking them rigidly into the shape the arm assumed before tensioning. Releasing the tensioning lever to a "loose" position, partially releases the cable tension, permitting the arm shape to be adjusted. Releasing the tensioning lever fully allows the cable to go slack, permitting the support arms to be folded flat against the platform for compact stowage. An attractive feature of this support arm concept is that it allows three-dimensional repositioning of the workstand, within the range limits of the mounting arms without requiring reconnection of the mounting arms to the structure.

ARTICULATED MOUNTING ARM CROSS-SECTION



PORTABLE WORKSTAND CONCEPT (Continued)

The concept for connecting the mounting arms to the structure is shown. The SSSAS studies indicate that structure is likely to be fabricated from longerons and struts whose representative dimensions and cross sections are summarized as follows:

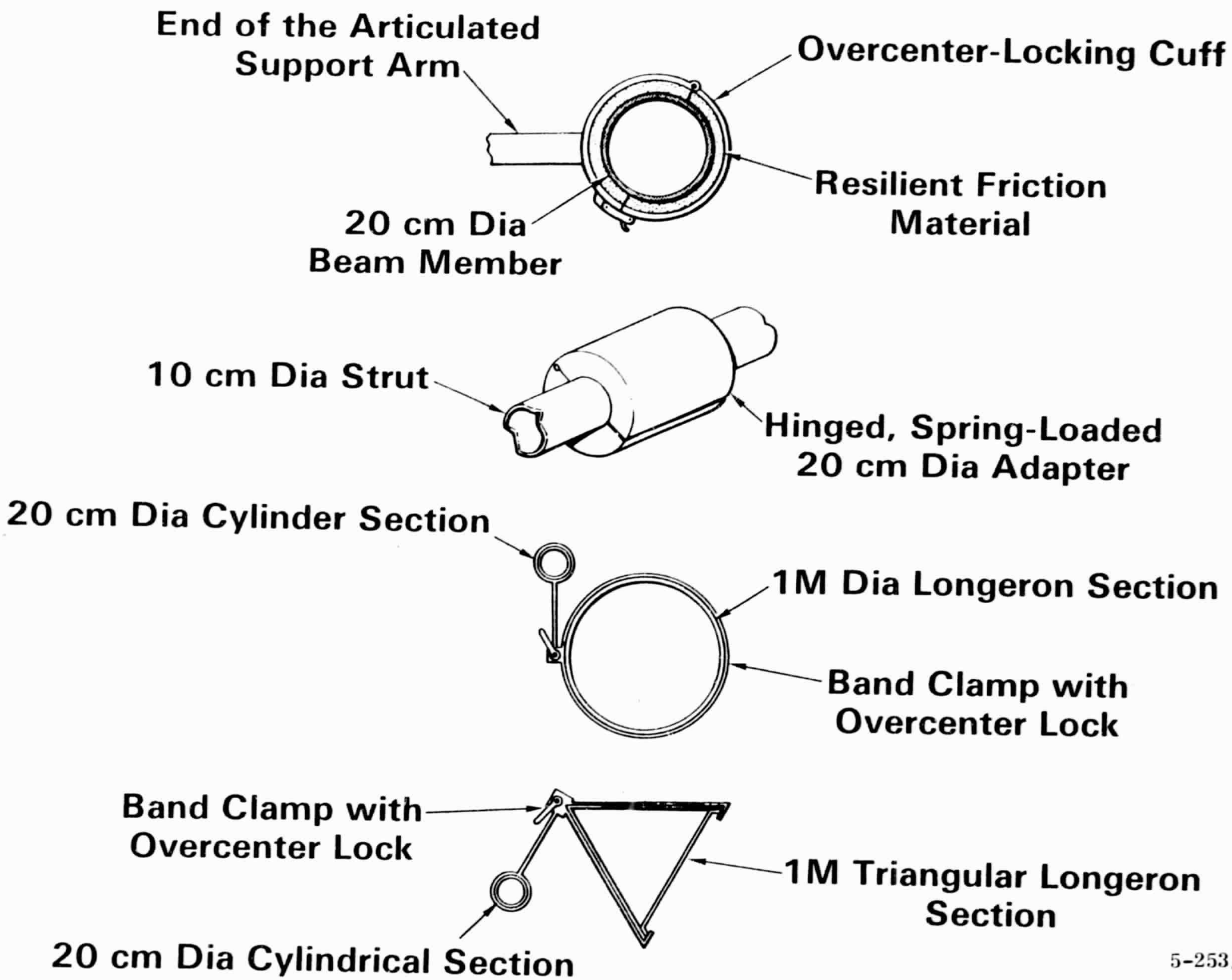
Beam Member	Cross Section	Size
Longeron	Circular	10 cm dia 1 m dia
	Triangular	1 m on a side
Strut	Circular	20 cm dia 10 cm dia

The portable workstand is required to be attached to the full range of these structural elements. The basic attachment element of the mounting arm is the overcenter-locking cuff, which is sized to attach to a 20 cm diameter cylinder. To anchor to a 10 cm diameter strut, an astronaut would first clamp a hinged, spring loaded, adapter over the 10 cm diameter strut to increase its diameter to 20 cm. Then the overcenter-locking cuff would be used as though it were attached to a 20 cm diameter strut.

To permit attachment to the 1m longerons, band clamps would be provided as shown. These are simple, temporary attachment points, secured with an over-center lock. Each band clamp has a short 20 cm diameter cylindrical section that interfaces with the overcenter-locking cuff.

These attachment arrangements require that no permanent special provisions be incorporated into the structure.

MEANS OF ATTACHMENT TO STRUCTURE



ECWS INTEGRATION

- Heat Rejection
- DCM Reduction
- Automatic Temperature Control
- Integration of Torso and LSS-TIM
- LSS Power from Work Site
- Maneuvering System Integration

HEAT REJECTION

Because non-expendable heat rejection means are bulky and heavy, efforts to minimize these effects drive some aspects of ECWS integration.

Peak Load Reduction - offers an opportunity to reduce the size of radiators and heat sinks as well as reduce the capacity of the heat transport loops and heat exchangers. Sunshades, shielding the EVA crewman from the full exposure to the sun, could conceivably eliminate a significant portion of the approximately 400 Btu/hr solar heat load, reducing the total heat load by upwards of 20%. Such a saving could translate into a reduction of 40 lbs and 0.6 ft^3 of PCM heat sink or 3 ft^2 of radiator surface.

Sun shield concepts can be portable or permanent. Portable shields are carried about by the crewman, and set up at his worksite. They are manually adjusted to keep the crewman shaded. Permanent shields are set up at long term worksites, and are larger, shielding a much larger portion of the worksite.

A thermal flywheel, consisting of 20 lb of water, could absorb 400 Btu/hr for approximately 30 minutes, rising 10° in temperature. This heat would be given off by the radiator, while on the orbit dark side. The thermal flywheel could be packaged as follows:

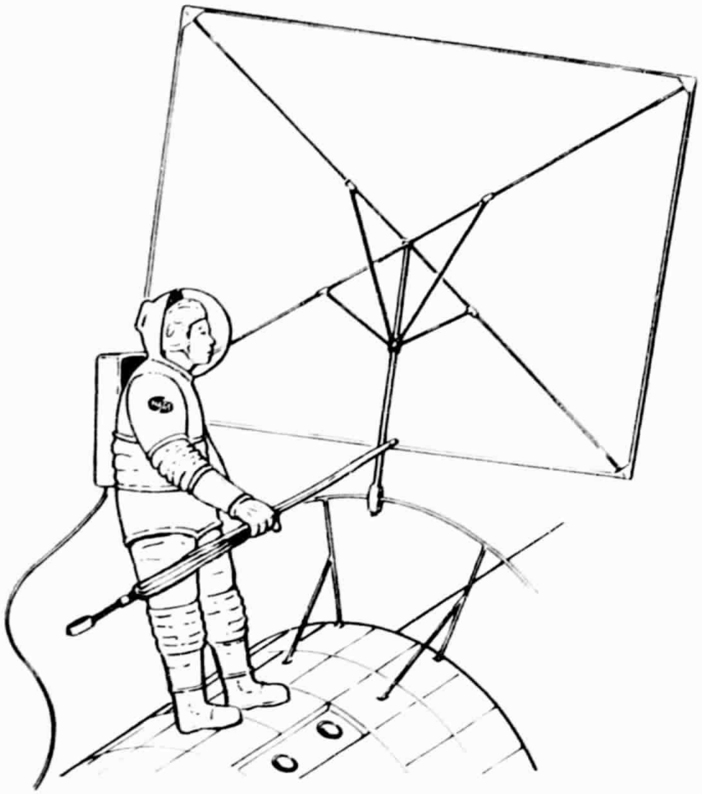
- Integrated into THRO, as a vest section where water would act as a supplemental insulation and radiation shielding, thus reducing the requirement for additional thermal shielding and for low Z, outer layer radiation protection.

- Integrated with the leg encasement as a water jacket, reducing the need for supplemental thermal insulation and radiation protection.

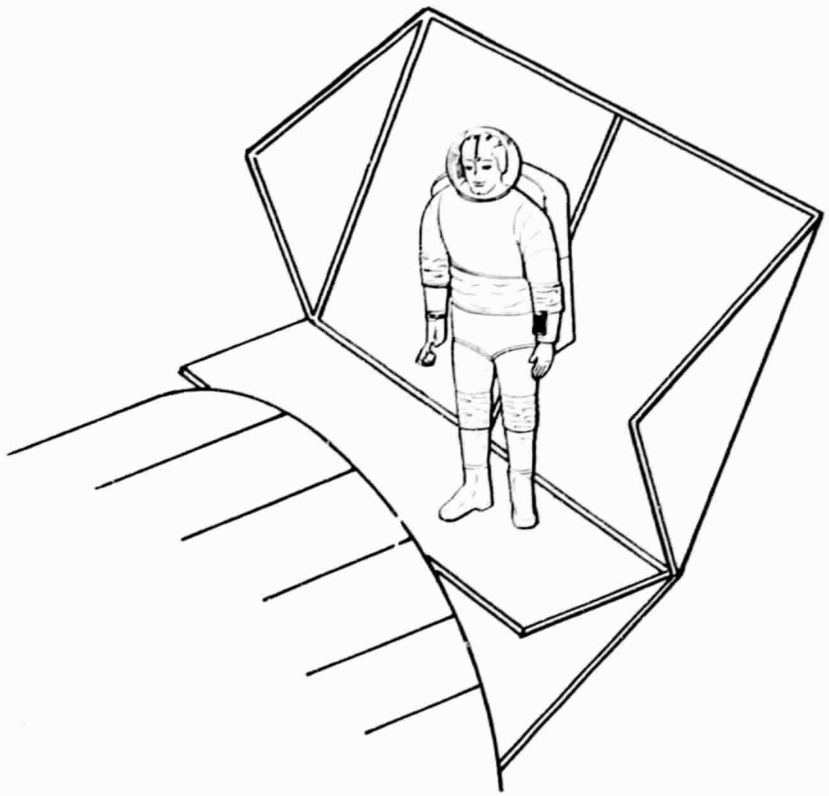
Radiator Integration offers an opportunity to reduce the inconvenience of handling a large, flat surface. The radiator may also serve as a sunshade, reducing heat leaks from the direction of the back, and adds low Z radiation shielding, reducing the amount of supplemental radiation shield required.

If rigid leg encasement is used, the external surface is available, which can provide the entire 15 ft^2 radiator area requirement.

SUN SHIELDS

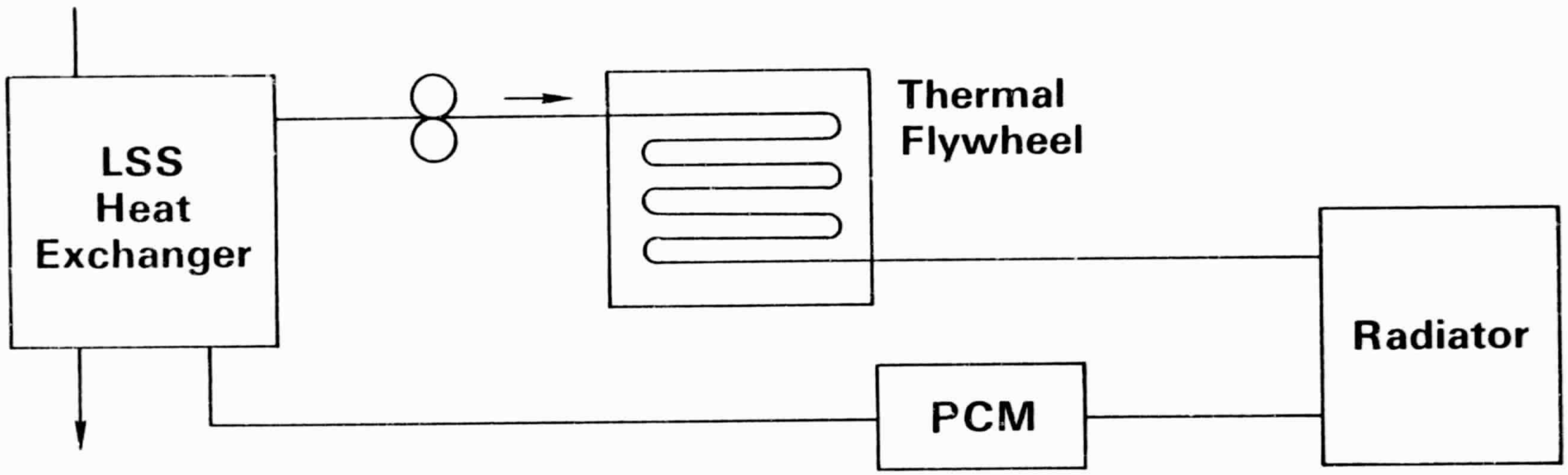


Portable

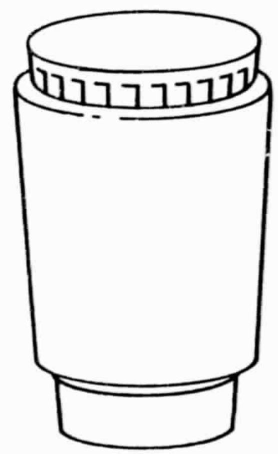


Permanent

THERMAL FLYWHEEL

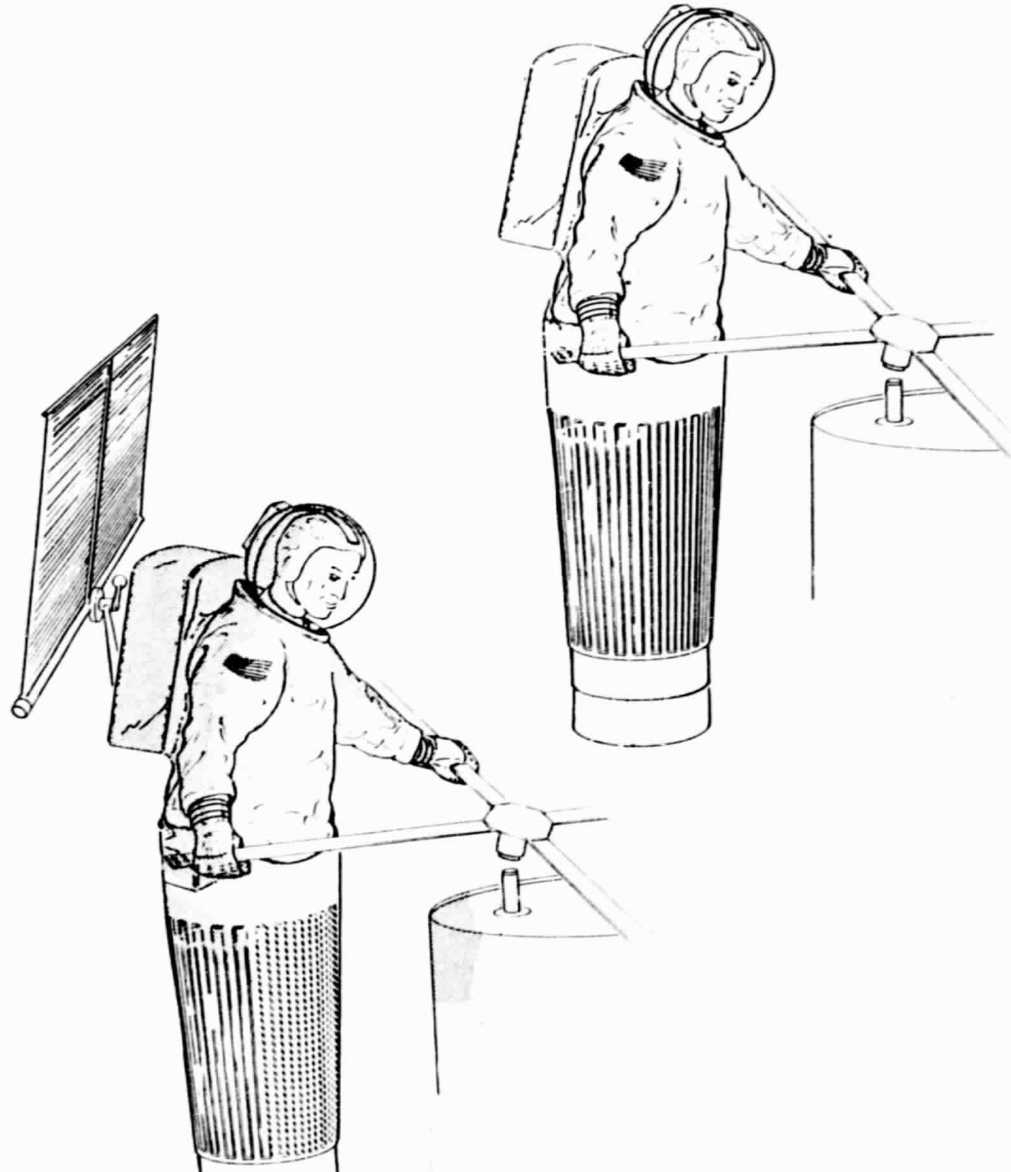


Integrated into THRO



Integrated into Leg Encasement

RADIATOR INTEGRATION

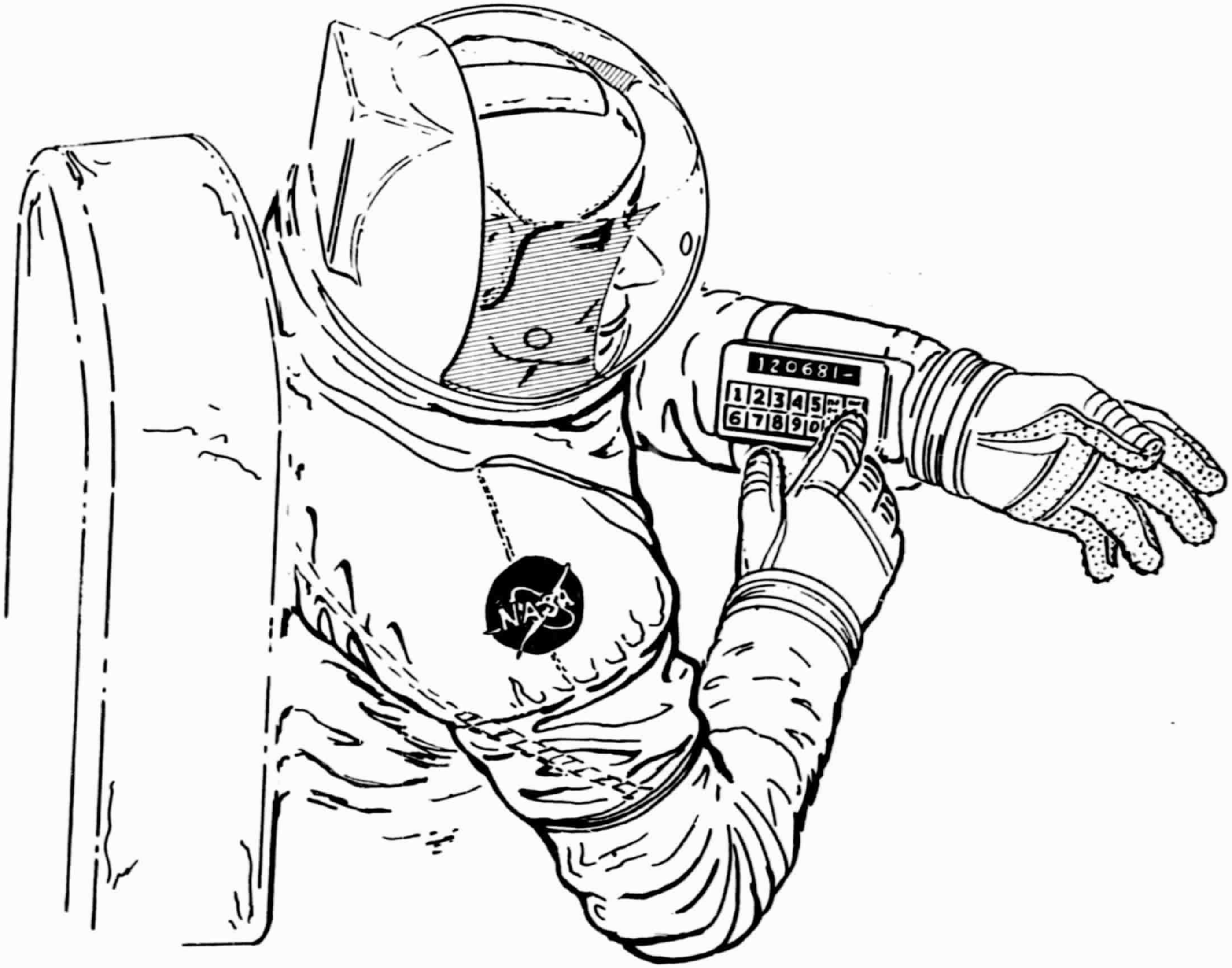


DCM REDUCTION

Advances in microprocessors and fiber optics offer the potential for eliminating the chestmounted DCM, and replacing it with a much smaller wrist-mounted keyboard and display. The key to this concept is to use the microprocessor to control the LSS, in response to inputs from the crewman inputted via the keyboard. Readouts are provided via the display, which uses information generated by the microprocessor, and transmitted either via electrical or optical lines to the readout.

Direct operating commands, such as ON-OFF, and communication modes would likely have dedicated buttons on the panel. Adjustments, such as temperature control and communications volume can be "ramped in" by activating a switch for a proportional length of time.

The advantages of this approach are savings in weight and volume, as the electronics are much smaller and lighter than the mechanical hardware that they replace.


120681-
1 2 3 4 5
6 7 8 9 0

AUTOMATIC TEMPERATURE CONTROL

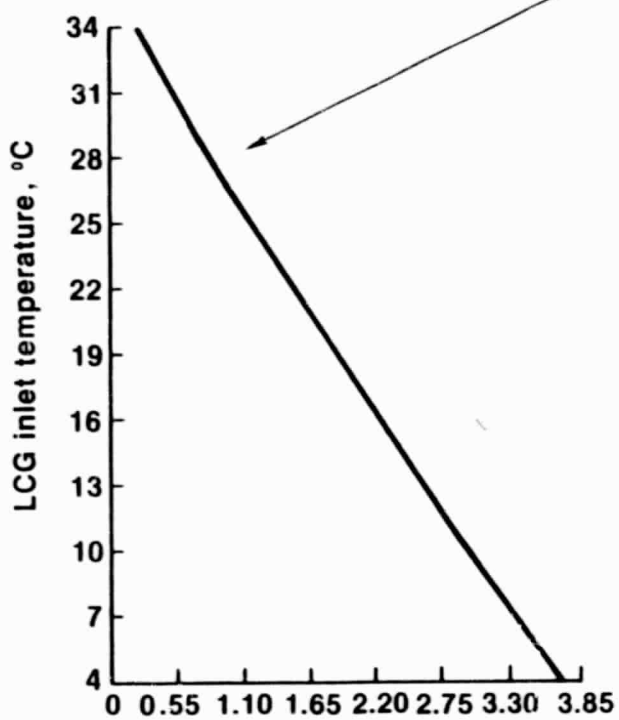
Use of the microprocessor to control LSS functions can be extended to automatic temperature controls. Based on work done at NASA/JSC, an automatic controller regulates LCG inlet temperature in response to LCG ΔT, maintaining the body temperature within the comfort zone. Transients are also accommodated by regulating ΔLCG inlet in response to LCG $\Delta(\Delta T)$.

Use of this concept further simplifies ECWS controls by eliminating the external temperature control adjustment, and this integrates well with the DCM reduction.

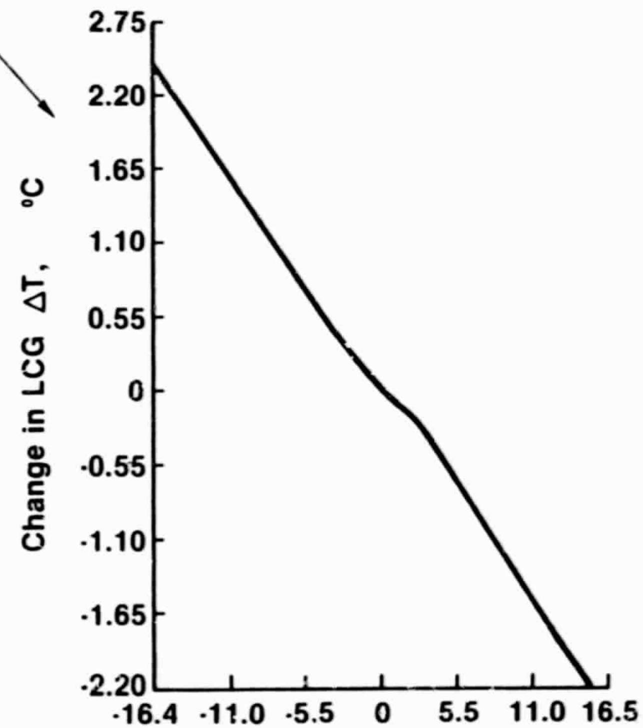
AUTOMATIC TEMPERATURE CONTROL TRANSFER FUNCTION

$$T_{in_{new}} = T_{in_{old}} + K_1 f_1 (\Delta T_{LCG}) + K_2 f_2 \left(K_3 E + K_4 \frac{dE}{dt} + K5 \int E\, dt\right)$$

$$E = \Delta(\Delta T_{LCG})_{act} \cdot \Delta(\Delta T_{LCG})_{exp}$$



LCG inlet temperature vs. ΔT at comfort level

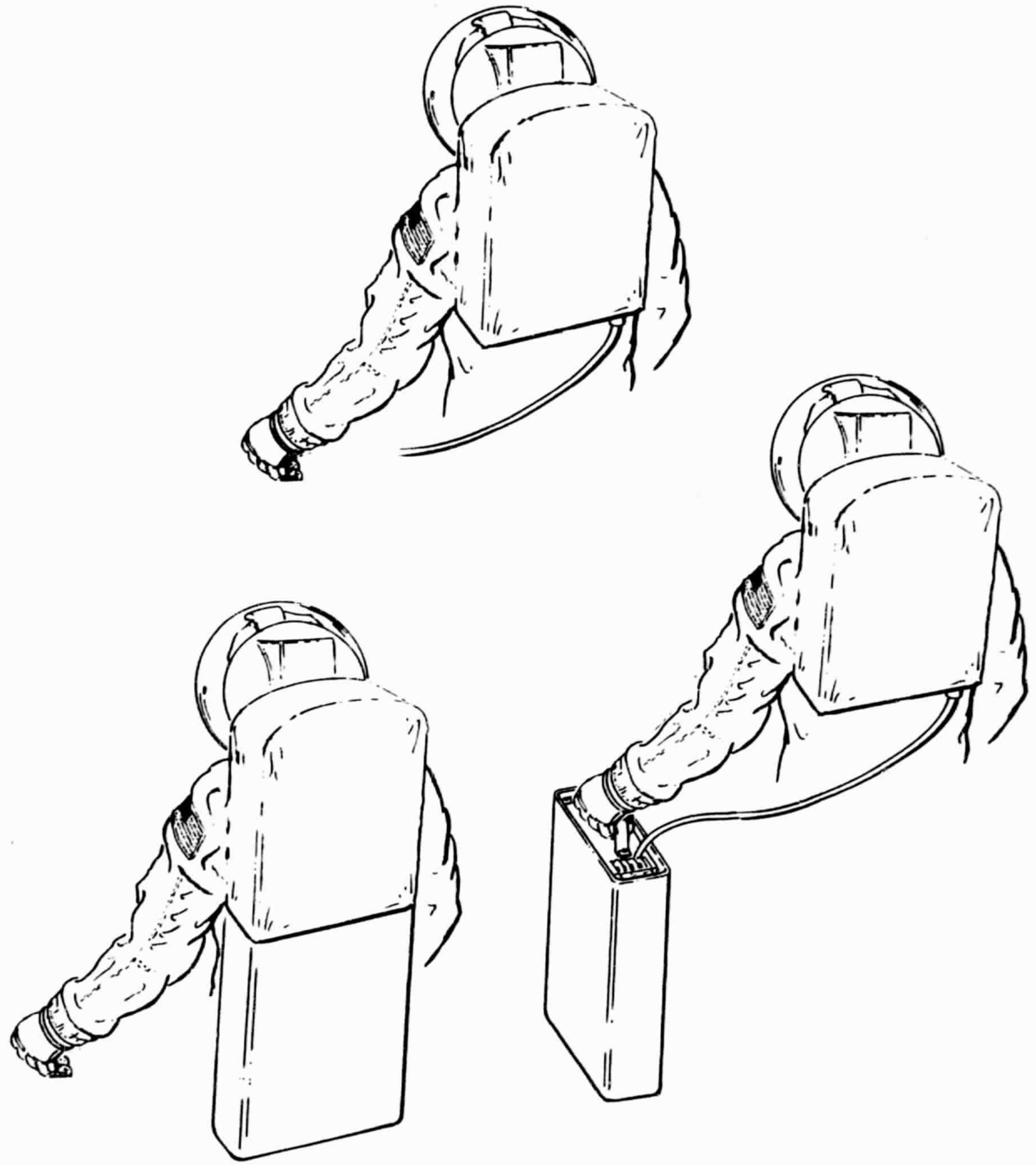


Change in LCG ΔT compared to change in LCG inlet temperature while comfort is tracked

INTEGRATION OF TORSO AND LSS TIM

Integration of the LSS TIM components within the torso eliminates the interface connections that exist between separable torsos and LSS's. This concept also provides hard shell protection around the TIM. Assembly and maintenance would be fostered by making the TIM components as modules, inserted through the openings of the neck, scye bearings, and entry closure.

INTEGRATED TORSO AND LSS-TIM



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LSS POWER FROM WORKSITE

Permanent, long term worksites will require power for lights and tools. Additional power to run the LSS is also expected to be available. Use of worksite power will reduce the LSS battery weight and volume requirement.

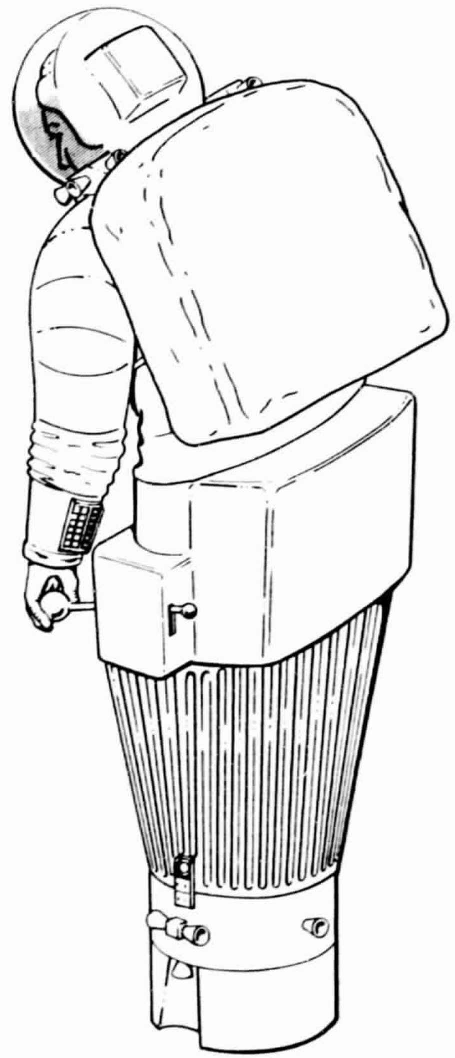
MANEUVERING SYSTEM INTEGRATION

Total integration with the maneuvering system is shown. In this concept, the controls and LSS TDM are integrated into the leg encasement, the outer surface of which is the radiator. Maneuvering system expendables and regenerable heat sink are located in the base, as modules.

Thrusters are mounted to the base and to the crewmember's shoulder. It is expected that thruster forces, which are on the order of several pounds, can be applied directly to the crewmember's body by the shoulder-mounted thrusters.

Rigid waist restraint is not expected to be necessary. The crewmember can be trained to stiffen the body in anticipation of thruster actuation.

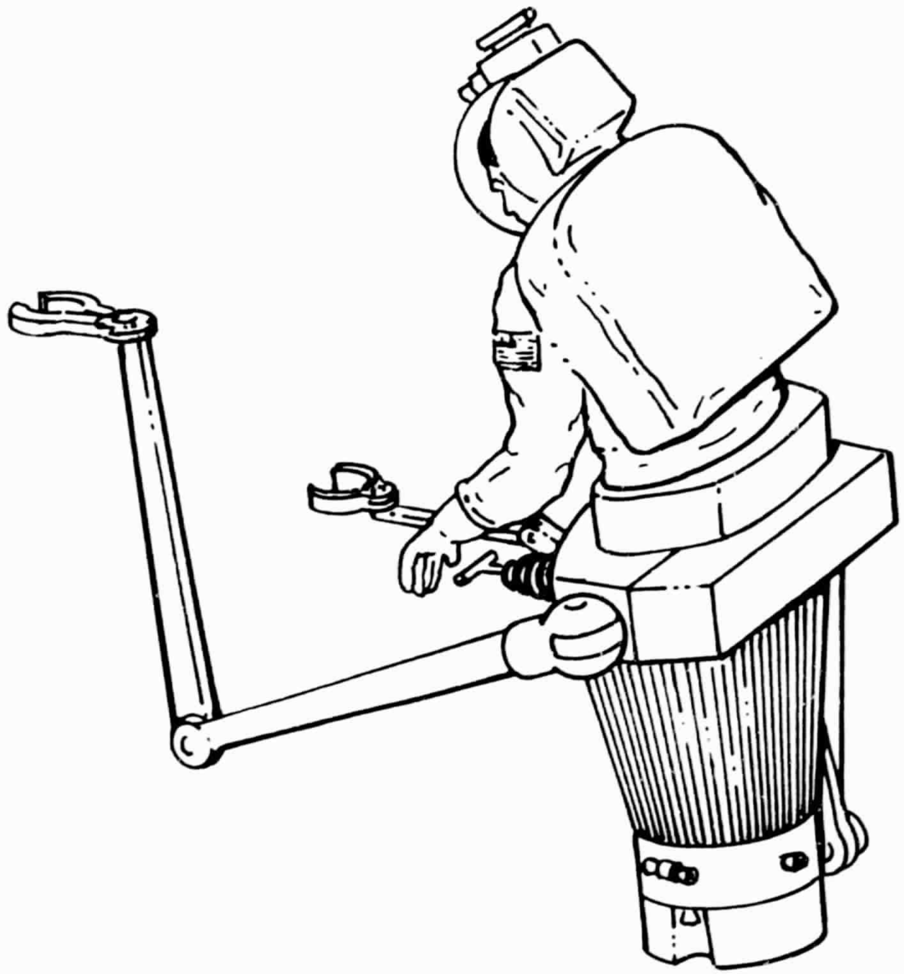
INTEGRATED ECWS AND MANEUVERING SYSTEM



OPTIONAL MANIPULATOR MODULE

Performing some heavy-duty tasks may be easier if a manipulator is used in place of the crewmember's hands and arms. The manipulator offers a stronger and more enduring grip and a longer reach than human hands and arms. The manipulator module concept, shown in this accompanying illustration, surrounds the crewmember's waist. It duplicates human arm and wrist motion, and has end-effectors capable of gripping and turning objects. The manipulator would be powered by its own rechargeable battery. When not in use the manipulator could be stowed on a bulkhead in the payload bay. When stowed in this manner the manipulator module becomes the stowage mount and donning station for the rigid leg encasement.

INTEGRATED ECWS AND OPTIONAL MANIPULATOR MODULE



EXTRAVEHICULAR CREWMAN WORK SYSTEM STUDY PROGRAM

Final Report, Volume 2, Construction

Introduction
Structure Characteristics
Construction Tasks
Requirements
Concept Evaluation
System Preliminary Design

HAMILTON STANDARD
Division of UNITED TECHNOLOGIES

INTRODUCTION

ECWS preliminary design presents analyses of size, weight, performance and interface considerations of the selected ECWS concept. The concept was selected from among the candidate subsystems that were identified and evaluated in Section 5. The selection of ECWS subsystems occurred after presenting the candidate subsystems to NASA in the "ECWS System Selection and Recommendation Presentation", Hamilton Standard SP03T78, October, 1978. NASA's selection of subsystems is confirmed in letter ECWS-052, dated 20 October 1978. The selected subsystems are:

EVA Enclosure

Helmet	-	Liquid Crystal Visor Concept
Upper Torso	-	Hard, with Single Plane Disconnect
Shoulder	-	Stove Pipe Joint
Elbow, Knee and Waist	-	Torroidal Joints
Glove	-	Modular concept with pin insulation
Soft Goods	-	Single Wall Laminate
Radiation and Thermal Protection	-	Thermal Hazards Radiation Overgarment - Required for High LEO and GEO
Lower Torso	-	Conventional Pants and "Leg Can"

Life Support

Primary Oxygen Supply	-	3000 psi gas
Emergency Oxygen Supply	-	6000 psi gas
Condensate Control	-	Slurper
Carbon Dioxide Control	-	K_2 CO_3 Membrane
Heat Rejection	-	Combined Radiator/Phase Change Material
Packaging	-	One Person, Convertible Package

Work Aids

Workstand	-	Portable Workstand Concept
Tool Adapter	-	Automatic Concept

EVA ENCLOSURE

The EVA enclosure is described in Section 5 of this volume. Major enclosure requirements that drive enclosure weight are:

- 10 year life
- 5,000,000 cycle life for major joints
- 8 psig operating capability
- On-orbit replacement of enclosure modules
- Radiation protection for selected orbits
- Leakge less than 30 scc/min at 4 psig.

Using enclosure modules of different sizes will permit fitting 5th to 95th percentile male and female crewmembers. Based upon present crews medium and large sized modules are expected to be used in the majority of cases. Hence, for the purposes of this study, EVA enclosure weight is based upon "large" size modules.

The following describes the EVA enclosure elements in more detail and presents weight and envelope information for a "large" size EVA enclosure.

Pressure Garment Assembly Element	Description	Weight
Hard Upper Torso (HUT)	- Single plane closure at waist - 8 psig capability met using high tensile material, such as Kevlar - Thermal insulation overcover	28 lbs
Arms (2)	- Single wall laminate softgoods with thermal insulation overcover - Separate primary and secondary neutral axis restraint cables and anchor brackets. Cables are of corrosion resistant steel - 4 bearing stovepipe shoulder - Bearings have forged steel races - Bearing diameters are 8.0 in. scye, 7.2 in. 1st intermediate, 6.5 in.. 2nd intermediate and 5.7 in. arm - Torroidal elbow bearing - Includes upper and lower arm sizing elements	40 (pair)
Lower Torso Assembly (LTA)	- Single wall laminate softgoods with thermal insulation overcover - Separate primary and secondary neutral axis restraint cables and anchor brackets. Corrosion resistant steel cables - Waist bearing has forged steel races - LTA includes boot modules - Torroidal knee and hip joints - Includes waist length and upper and lower leg sizing elements	55
Gloves (2)	- Single wall laminate softgoods with molded elastomer pin standoffs for thermal insulation - Torroidal wrist joint - Rolling convolute 1st metacarpal joints for thumb and fingers - Three module construction	6 (pair)

Pressure Garment Assembly Element		Description	Weight
Liquid Cooling and Ventilation Garment (LCVG)	-	Mesh "union suit" with liquid cooling tubes and ventilation ducts	6
	-	Worn over chiffon body stocking	
Urine Collection Device	-	Similar to Shuttle EMU	1
In-suit Drink Bag	-	Similar to Shuttle EMU	
	-	21 oz capacity	
Communications Carrier Assembly	-	Similar to Shuttle EMU	
Total Pressure Garment Assembly			136 lbs

RADIATION PROTECTION

Radiation protection consists of modular overgarment sections available in various sizes and thicknesses. Modules consist of arms, overgloves, upper torso and lower torso with legs and feet. Module sizes accommodate projected size range of crewmember population. Module thicknesses cover range of projected orbital altitudes and inclinations. Thicknesses are designed to protect for 154 8-hour EVA's at designated orbits. Mechanical hazards protection is provided by tough outer layers. These layers are also of relatively low atomic weight to slow down incident electrons. Dense, high atomic weight inner layers complete the radiation shielding.

In actual practice radiation protection layers, as required, would be interleaved with layers of thermal insulation. Because thermal insulation is always required, regardless of orbit, its weight has been included with the PGA sections in the preceding tabulation. Weight for incremental radiation protection is presented in the following tabulation.

	ORBIT			
	28 1/2°	55°		GEO
	500 km	400	500	36K
Radiation Shielding	8	16	24	63 lbs

OPTIONAL RIGID LEG ENCASEMENT

Rigid leg encasement (leg can) offers several advantages for free flying EVA sorties. First, mechanical and radiation hazards protection can be provided in rigid metal, which is a simpler construction than flexible trousers. Second, the LSS radiator can be integrated with rigid leg encasement.

The leg can is unpressurized, and is stowed outside the air lock when not in use. This saves room inside the vehicle and keeps the fluid-filled radiator outside. The crewmember wears a pressurized LTA without a hazards-protective overgarment. In an emergency that requires leg mobility, the crewmember can jettison the leg can and return to the vehicle using the refreezable PCM heat sink. The radiation dose from a single four-hour exposure is not expected to be serious.

Integrating the radiator with the leg can allows the radiator material to contribute to radiation shielding. A leg can with radiator for LEO use is estimated to weigh 27 lbs and 41 lbs for GEO use. Its envelope is 16 in. wide x 14 in. deep x 52 in. high.

HELMET

The helmet concept is a clear polycarbonate bubble equipped with liquid crystal panels to provide automatic visoring. The concept is described in Section 5 of this volume. Radiation protection is provided by making the helmet sufficiently thick. For LEO use the helmet should be 0.1 in. thick. The estimated weight is 7 lbs. For GEO use the helmet is 0.5 in. thick and weighs 13 lbs.

Total space suit assembly weight estimates including helmet are shown in the accompanying tabulation. Estimated size envelope for a "large" space suit assembly with flexible legs is 74 in. tall x 32 in. wide across the shoulders x 14 in. deep across the body seal closure at the waist.

SPACE SUIT ASSEMBLY WEIGHT ESTIMATES

	ORBIT				
	28 1/2°		55°		GEO
	400 km	500	400	500	36K
Pressure Garment Assembly	136	136	136	136	136 lbs
Radiation Protection	0	8	16	24	63
Helmet	7	7	7	7	13
Total Space Suit Assembly with Flexible Legs	143	151	159	167	212 lbs
Pressurized Garment Ass'y	136	136	136	136	136 lbs
Radiation Protection without Legs and Feet	0	4	9	13	43
Leg Can with Radiator	27	27	27	27	41
Helmet	7	7	7	7	13
Total Space Suit Ass'y with Integral Radiator and Leg Can	170	174	179	183	213 lbs

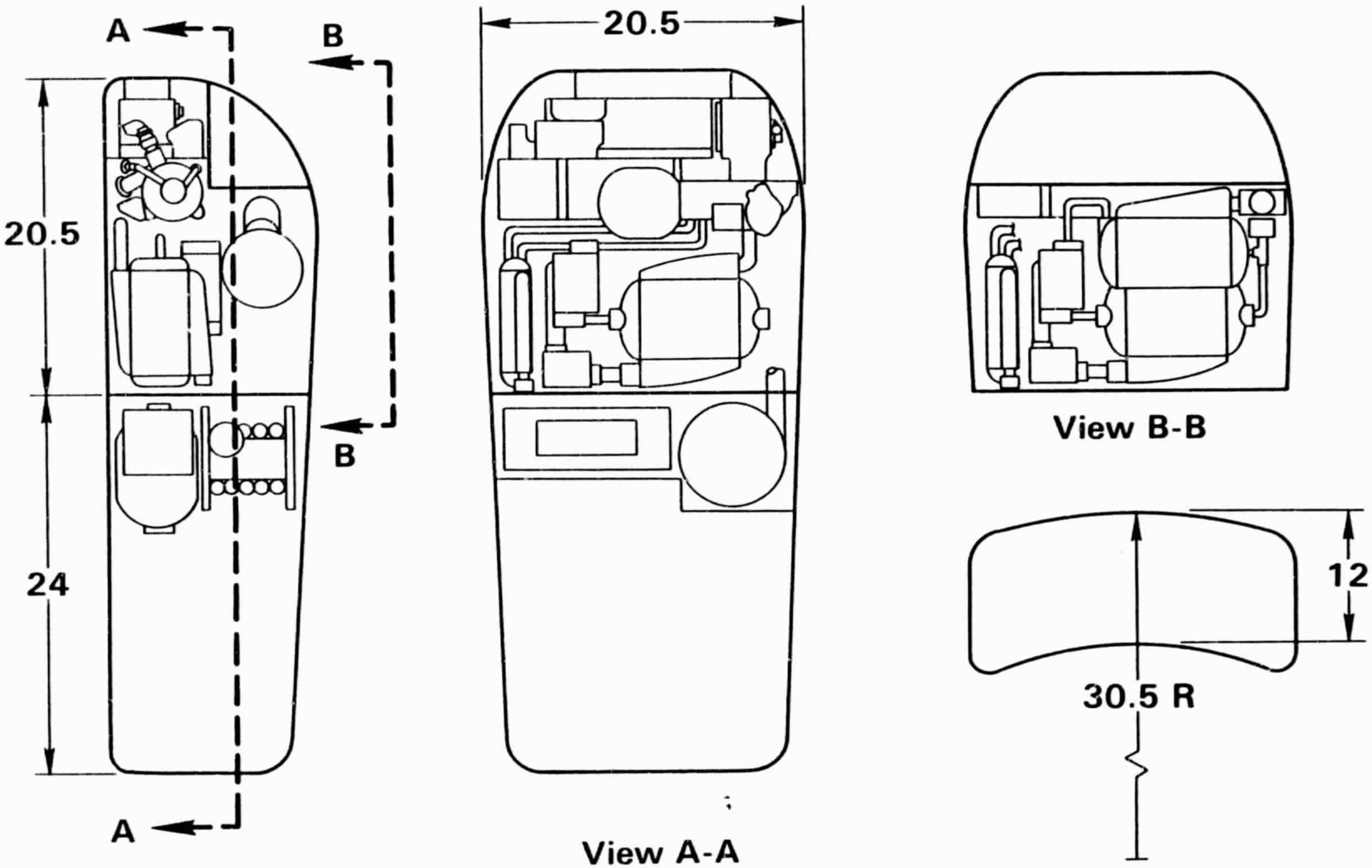
LIFE SUPPORT SYSTEM

The life support system is described in Section 5 of this volume. Major life support requirements that drive weight and volume are:

- 8 hour EVA duration
- 1,000 Btu/hr average metabolic rate
- 1,600 Btu/hr peak metabolic rate
- 4 to 8 psig operating capability
- 7.6 mm Hg CO_2 concentration
- 1/2 hour emergency capability
- Regenerable CO_2 removal
- Non-venting heat sink
- Convertible packaging

The life support system consists of two packages. One package is always worn on the back, and contains the safety functions (emergency subsystem, caution and warning subsystem and communications subsystem) and atmosphere revitalization functions (CO_2 removal, ventilation and humidity control). The second package may be worn two ways; either close-coupled to the ARS-safety package or hand carried by the crewmember to be set down at the worksite. The second package contains basic service functions (cooling, make-up O_2 and power).

LIFE SUPPORT SYSTEM PACKAGING CONCEPT



ITEM	DESCRIPTION	WET WEIGHT-LB
Safety and Atmosphere Revitalization Function	Conformal package mounted to Space Suit Assembly Hard Upper Torso. Package dimensions are 20.5 in. side-to-side x 20.5 in. high x 12 in. front-to-back. Back surface is curved on 30.5 in. radius to conform to airlock wall with 1 in. clearance.	104 lbs
Communication System	Radio similar to Shuttle EMU EVC. Antenna similar to Shuttle EMU.	
Valve Module Manifold	Mounts gas and water valves and fan-pump-separator. Similar to Shuttle EMU.	
Valves and Regulators	Similar to Shuttle EMU O_2 valves, regulators and condensate management valves.	
Heat Exchanger	Three fluid heat exchanger using the PCM/Radiator loop to cool suit vent and LCVG loops.	
Rotating Machinery	Fan, pump and water separator driven by a single modular DC motor. Similar to Shuttle EMU.	
Caution and Warning System	Microprocessor system controls LSS and annunciates faults and procedures. Has additional capability for supporting EVA tasks.	
Automatic Valve Actuators	Hardware to drive LSS valves via microprocessor control.	
CO_2 Removal Subsystem	K_2CO_3 - membrane concept.	
Emergency Subsystem	Similar to Shuttle EMU SOP.	
Structure	Impact shields and primary structure.	
Thermal Insulation	Multi-layer package cover.	

ITEM	DESCRIPTION	WET WEIGHT-LB
Basic Services Package	Separate package can be worn two ways, either mounted directly to bottom of safety and ARS package or hand carried. Can be set down at worksite to reduce on-the-back bulk. Package dimensions are 20.5 in. side-to-side x 24 in. high x 12 in. front-to back. Back surface is curved on 30.5 in. radius.	136 lbs
Primary GOX Supply	Single 3,000 psi filament-wound tank. Usable capacity is 1.36 lb O_2.	
Battery	Silver-zinc alkaline battery, providing 18 amp-hr at 18 VDC. Capable of at least 80 deep discharge-recharge cycles.	
Phase-Change-Material Heat Sink	Refreezable, capable of handling 1,668 Btu/hr average heat load for 4 hours. Includes pump and motor.	
Umbilical	25 ft umbilical provides high pressure O_2, power, tether and cooling water. Includes locking reel.	
Structure	Impact shields and primary structure.	
Thermal Insulation	Multi-layer package cover.	
Total Weight for ARS and Safety Functions Package Plus Basic Services Package		240 lbs
Radiator	Separate 15 ft^2 radiator for use with space suit assembly equipped with flexible legs. Radiator consists of 3 folding panels, lines, with disconnects and arms for mounting to structure.	25 lbs
Total for Life Support System Including Separate Radiator		265 lbs.

PORTABLE WORKSTAND

The portable workstand consists of a telescoping backbone which is fastened to structure by articulated mounting arms. A foot-restraint plate, similar to the plate in the Shuttle air lock, can be attached to various locations along the backbone using pip-pins. The articulated mounting arms permit adjusting the workstand location with respect to structure. Once adjusted the workstand is locked into position by tensioning cables inside the articulated mounting arms. The arms are fastened to the structure by overcenter locking cuffs. The workstand includes lighting and storage for tools and materials. The concept is described in Section 5 of this volume.

Portable Workstand Element	Description	Weight
Backbone with Foot Restraint and Equipment Mounts	Telescoping bar with mounting provisions for LSS Radiator and basic service package, flood-lights and stowage for tools and materials. Bar extends to 84 in. and collapses to 60 in. Includes foot restraint plate.	
Articulated Mounting Arms, Locking Cuffs and Adapters for 10 cm dia Tubular Structure	Three sets of 48 in. articulated mounting arms with internal tensioning cables. Locking cuffs accommodate 20 cm dia tubular structure. Adapters accommodate 10 cm dia tubular structure.	
Stowage Locker	Stowage locker is 18 in. side-to-side x 12 in. deep x 36 in. high, and contains 3 perforated shelves to which tools and supplies are fastened with clips.	
Lights	Two 15 watt 4 in. dia lights that are bracketed to the mounting arms.	
Battery	18 volt, 18 amp hr, 60 watt, silver zinc battery identical to LSS battery.	
Adapters for Large Structure	3 adapters fastening to 1 m circular and triangular cross section structure.	
Total Weight for Portable Workstand		52 lbs

Folded workstand envelope is 60 in. x 16 in. x 18 in.

POWER TOOL ADAPTER

The power tool adapter is a hand-held motor and drive unit. It powers separate tool modules for drilling, fastener driving and cutting operations. The tool adapter provides two motor speed ranges. Reciprocating motion and foreward or reverse rotary motion can be selected. Representative motion performance requirements are as follows:

Tool Function	Motion	Speed	Motor Hp
Drill	Rotary CW	50-900 rpm	0.33
Socket Drive	Rotary CW and CCW	5- 50 rpm	0.12
Hacksaw	Reciprocating	170 cpm	0.22
Pop Rivet	Reciprocating	50 cpm	0.02

Two silver-zinc batteries identical to the LSS batteries power the tool adapter. The motor is cooled by a "cold clip" mounted on the radiator. The tool is stowed in the "cold clip" when not in use. Intermittent cooling provided by the cold clip is consistent with an anticipated intermittent duty cycle.

Weights and volumes of the power tool adapter are per the accompanying tabulation.

Power Tool Adapter Element		Description	Weight
Motor-Drive Unit	-	Aluminum housing containing motor, control electronics and reciprocating/rotary motion drive train.	8 lbs
	-	Steel bearings, shafts and linkages	
	-	10,000 hrs useful life	
	-	Envelope is 10 in. long x 3 in. wide x 6 in. high at the handle. Controls include trigger ON-OFF switch, speed and mode selection and tool adapter release.	
Drilling Adapter	-	Drill magazine feeds drill bits up to 1/4 in. dia. into self-locking chuck.	6 lbs
	-	Includes debris collection provision. Envelope is 5 in. long x 3 in. wide x 4 in. high exclusive of debris collection.	
Fastener Driver Adapter	-	Magazine feeds various styles of fastener driver bits into self-locking chuck. Envelope is 5 in. long x 3 in. wide x 4 in. high.	3 lbs
Socket Wrench Adapter	-	Adjustable socket accommodates hex nuts and bolts from 1/2 in. to 1 in.	2 lbs
	-	Envelope is 2 in. x 2 in. x 5 in. long.	
Hacksaw Adapter	-	6 in. hacksaw for cutting metallic and composite materials.	5 lbs
	-	Envelope is 3 in. x 3 in. x 8 in. exclusive of debris collection.	
Battery Pack	-	2 silver zinc batteries identical to LSS batteries Envelope is 12 in. long x 7 in. wide x 6 in. high.	24 lbs
Total Weight for Power Tool Adapter and Listed Attachments			48 lbs

ECWS THERMAL PERFORMANCE

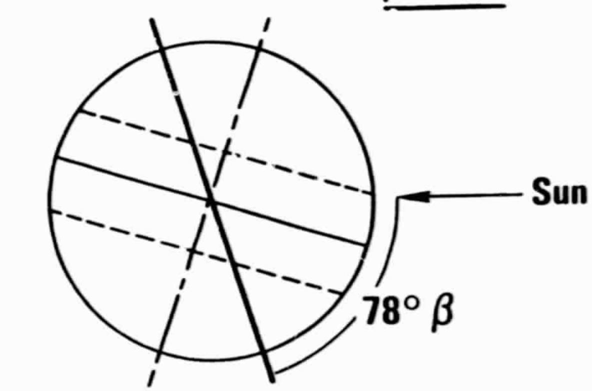
Environmental heat leaks were calculated for ECWS using TRASYS and EMU-SINDA computer programs. The accompanying illustration shows hot, cold and nominal cases for representative construction orbits. Representative structure configurations are also reflected. Heat leakage is based on suit insulation equivalent to the Shuttle EMU.

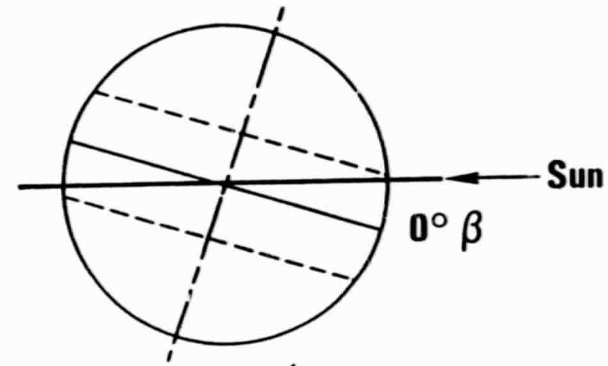
Flow charts for ECWS performance are shown for hot, cold and nominal cases. Environmental heat leaks have been increased by a 10% safety factor.

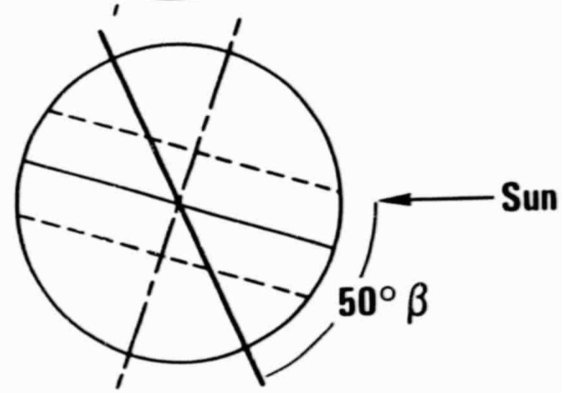
ORBITAL HEAT LOADS

Case	Orbit	Structure	Average Heat Load
Hot	55° 400 km	Crewmember on Sun Side of 30 x 270m Solar Panel	125 Btu/Hr into ECWS
Cold	23½° 500 km	Crewmember in Shadow of 30 x 270m Solar Panel	332 Btu/Hr Out of ECWS
Nominal	26½° 400 km	Crewmember is 50% Shaded by Truss 270m x 10m. Major Truss Member is 1m Dia	281 Btu/Hr Out of ECWS

β Angle

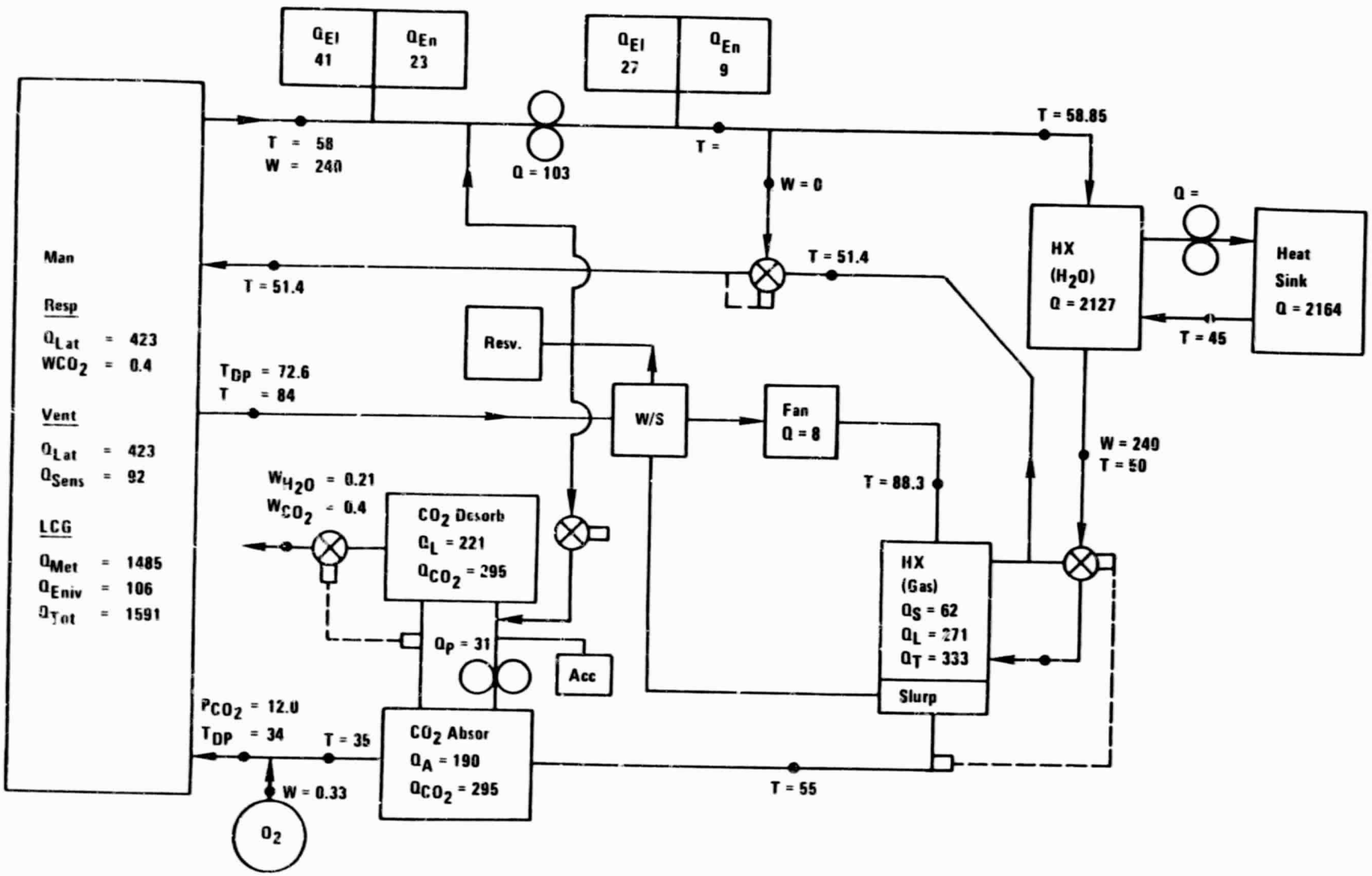






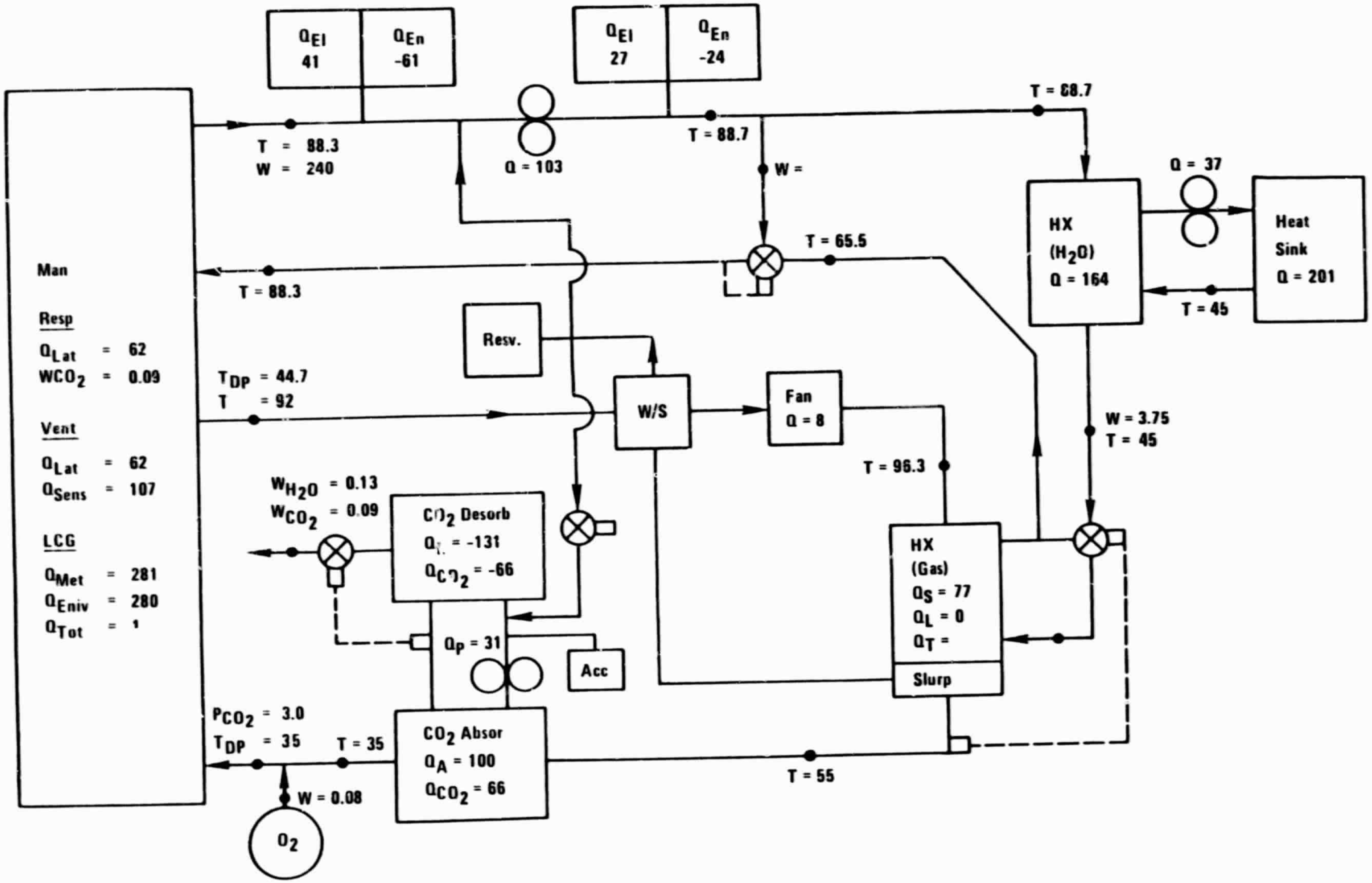
ECWS FLOW CHART

$Q_{Met} = 2000 \quad Q_{Envir} = 138$



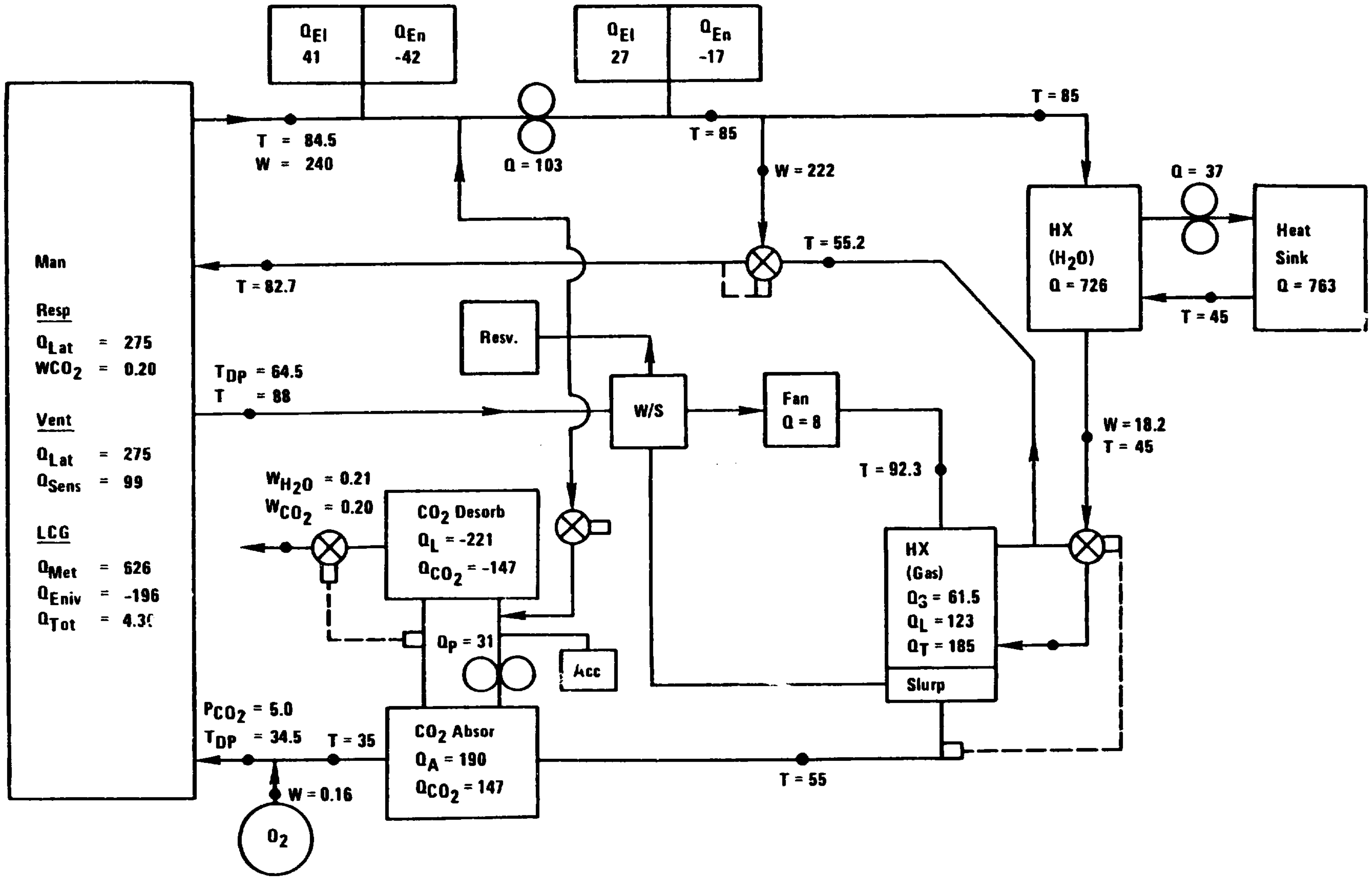
ECWS FLOW CHART — MINIMUM

$Q_{Met} = 450 \quad Q_{Envir} = -365$



ECWS FLOW CHART — NOMINAL

$Q_{Met} = 1000 \quad Q_{Envir} = -255$



ECWS INTERFACES WITH HABITATION MODULE

Space Station System Analysis Studies project use of the Orbiter air lock or derivatives in the habitation module. Accordingly, the ECWS preliminary design uses the Orbiter air lock as a baseline. The accompanying sketches show that adequate space exists for stowing two ECWS's in the air lock, and that a suited crewmember can pass through the air lock hatch.

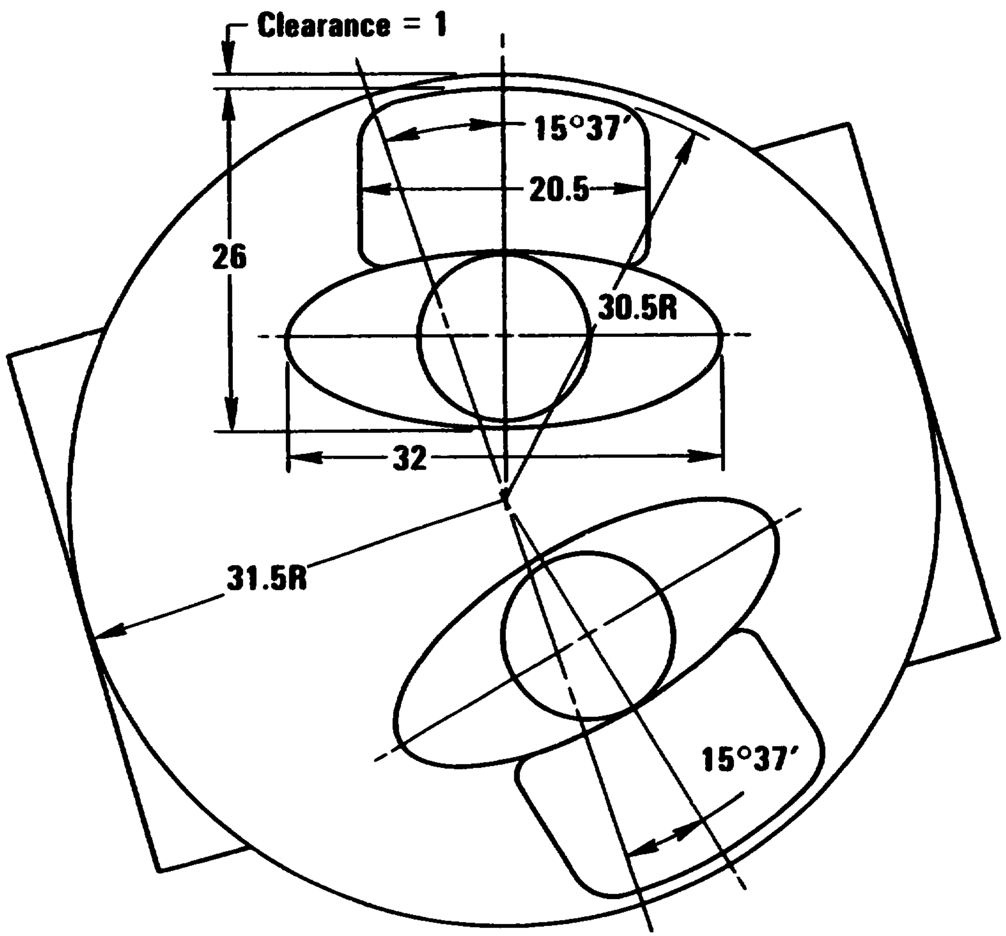
The ECWS's can be mounted to the air lock wall with air lock adapter plates (AAP) that are similar to the Shuttle EMU. Because the ECWS LSS is taller than the EMU PLSS and SOP, the AAP's will extend closer to the air lock's 1-g floor. This will require relocating the two sets of AAP-to-air lock dovetail fittings in the air lock wall structure.

A pair of service and cooling umbilicals will be required to provide cooling, power and communications during air lock operations. Battery recharge power, O_2 recharge and a condensate draining will also be provided by the umbilicals.

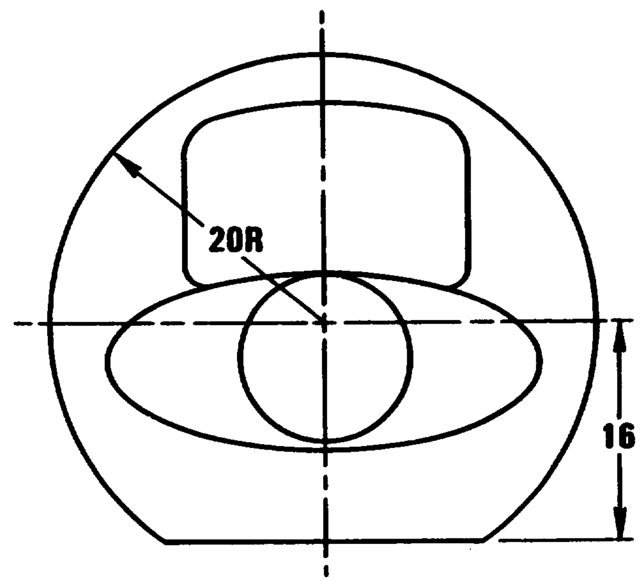
Consummables to support EVA consist of 3000 psi O_2, cabin gas to pressurize the air lock and 18 VDC electric power to recharge batteries. The accompanying tabulation quantifies consummables usage.

The heat sink phase change material (PCM) requires refreezing between EVA sorties. Based upon using the PCM for 4 hours per EVA at nominal heat loads and metabolic rates, refreeze will require removing an average of 3,100 Btu's from each PCM after each EVA sortie. Refreeze provisions will be required for each PCM in or adjacent to the air lock.

ECWS Stowage in Shuttle Airlock



Passage Through 1m Dia Hatch



ECWS CONSUMMABLES REQUIREMENTS

	Per EVA Sortie	Per 90 Day Resupply Mission (1)
Gaseous O_2 at 3,000 psi	1.364 lb	420 lb
Cabin O_2/N_2 Gas for Air Lock Repressurization	5.5 lb (2)	1,700 lb
Electric Power 18 VDC for Complete Battery Recharge (3)		
LSS	324 watt hour	100 kw hour
Workstand Lights	324 watt hour	100 kw hour
Power Tool	648 watt hour	200 kw hour
	1,296 watt hour	400 kw hour

(1) Mission use is based on 4 EVA crewmembers performing 77 EVA sorties each during a 90-day resupply period.

(2) Based on 2-person EVA teams, leaving the air lock unpressurized during EVA. 150 ft^3 air lock contains 11 lbs O_2/N_2 at 14.7 psia and 75°F.

(3) Each EVA crewmember is supported by 4 batteries: 1 for LSS, 1 for lights and 2 for power tool.

ECWS INTEGRATION WITH STRUCTURES

Structure characteristics drive several important features of the ECWS. These features have been addressed in Section 5 of this volume, but are summarized here.

- Surface Temperature Range: -180° to +200°F. EVA glove "pin" insulation will handle these extremes.
- Structure Size: Built up from elements up to 10m long. Elements may be positioned by 2 person EVA crews. Handling large elements drives wide angle visibility requirements. Handling large elements with both hands drives requirement for automatic visor operation. Structure length up to 250m long. Influences selection of 30 minute duration of emergency subsystem capability.
- Rough, Sharp Edges: Drives requirement for mechanical hazards protection in overgarment.
- Work in Shadow of Earth or structure: Drives requirement for workstand lighting.
- Fixed Worksites: Makes worksite power attractive for lighting and tool use.
- Handholds and Restraints: Structural element cross sections are reflected in locking cuffs for workstand attachment. Structure elements to be handled require handholds.
- Construction Tasks: Define strength, mobility and skill level requirements.

ECWS LIFE

ECWS life requirements are based on 10-180 day missions conducted in 10 calendar years. Cycle life requirements are based on 154 EVA sorties per mission. Most ECWS elements are expected to meet these requirements. However, the following elements are not expected to meet these requirements. Weight estimates are given for those items which are expected to require replacement or resupply during a 180 day.

- Batteries - Practical design limits life to 80-100 recharge cycles. Batteries require replacement every 90 days. 90 day replacement weight for four batteries is 48 lbs.

- Body Stocking - Chiffon liners worn under LCVG. Expected to last for 7 EVA's. Will require 11 sets every 90 days. 90 day replacement weight is 6 lbs.

- EVA Gloves - May require replacement depending on use. Assume 2 sets every 90 days. 90 day replacement weight is 12 lbs.

- Tool Bits - Expected to be dull or worn out before end of 90 day resupply period. Assume 3 sets every 90 days. 90 day replacement weight is 12 lbs.

- Hazards Protection - May be significantly worn at end of 180 days. Assume replacement on Earth between missions.

- LCVG - Expected to be significantly worn at end of 180 days. Assume replacement on Earth between missions.

Project total weight of limited life ECWS items for each crewmember is 78 lbs every 90 days.

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